UNIVERSITÀ degli STUDI di CATANIA | Dipartimento di Agricoltura, Alimentazione e Ambiente
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# UNIVERSITÀ DEGLI STUDI DI CATANIA

AGRICULTURAL FOOD AND ENVIRONMENTAL SCIENCE

XXXIII CICLO

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# Testing Commitment Costs theory in the purchasing process of Digestate: Empirical evidences from an economic experiment

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*“There is only one good,*
*Knowledge,*
*and one evil,*
*Ignorance.”*
*(Socrate)*

***Abstract***

*The aim of my PhD project is to elicit farmers' willingness to pay for the digestate, an organic soil conditioner obtained after anaerobic digestion process, that can be used as an alternative to chemical fertilizers to improve soil fertility.*

*The research study was subdivided in two phases.*

*In the primary phase of this research (preliminary phase), I have evaluated the potential production of Sicilian bio-methane produced in accordance with the Biogasdoneright™ principles. So, I highlighted that there is a big potential for the biogas sector, and this condition will determine a big production of digestate. So, the second phase started.*

*The second phase was an experiment to answer to three research questions. In particular, through a second price experimental auction, Sicilian farmers' willingness to pay (WTP) for digestate was elicited. Moreover, the influence of the variation of the degree of information about digestate on the farmers' WTP was studied in deep. In particular, to test the Commitment Cost theory, I evaluated whether waiting for additional future information on digestate would influence their WTP. Finally, I evaluated the correlation of some typical attributes for soil organic improvers with the WTP values.*

*The results show the existence of a positive farmers' willingness to pay for digestate and a delay effect value arising from the option value of being able to wait and learn more about the value of the digestate. Moreover, I put in evidence that some specific attributes investigated have influence on farmers' WTP.*

*This implies the necessity for policy makers to provide farmers with an appropriate level of information about the digestate's attributes.*

***Sommario***

*Il presente studio ha l’obiettivo prevalente di valutare la disponibilità a pagare degli agricoltori per il digestato, un ammendante organico ottenuto al termine del processo di digestione anaerobica, che può essere usato come alternativa ai fertilizzanti chimici per migliorare la fertilità del suolo.*

*Lo studio è stato articolato in due fasi.*

*Nel corso della prima fase, è stata valutata la potenzialità produttiva di biometano ottenibile in Sicilia, se venisse adottato il sistema basato sul rispetto dei principi del modello “Biogas fatto bene”. È stato evidenziato che esiste un grande potenziale inespresso di disponibilità di biomasse per la produzione di biometano e, se venissero realizzati gli impianti di digestione anaerobica, ci sarebbe una grande disponibilità di digestato per gli agricoltori. Accertata tale disponibilità, la seconda fase della ricerca è stata avviata.*

*Per rispondere a tre diverse domande di ricerca, è stato organizzato un vero e proprio esperimento. In particolare, attraverso un’asta sperimentale di secondo prezzo, è stata elicitata la disponibilità a pagare (DAP) per il digestato, da parte di agricoltori siciliani. Inoltre, è stato valutato l’effetto della variazione del grado di informazione fornita a proposito del digestato, sulla loro DAP. In particolare, per testare la teoria dei Commitment Cost, è stata valutata l’influenza dell’attesa, prima di ricevere ulteriori informazioni future sul digestato, sulla loro DAP. Infine, è stata valutata l’intensità della correlazione tra alcuni attributi specifici degli ammendanti organici e la DAP degli agricoltori intervistati.*

*I risultati della ricerca pongono in evidenza che esiste sia una disponibilità a pagare per il digestato, ed è positiva, sia un valore dell'effetto di “ritardo” derivante dalla possibilità di*

*poter attendere e conoscere meglio il valore del digestato. Inoltre, alcuni degli attributi considerati hanno avuto influenza sulla DAP degli agricoltori.*

*Tutto ciò implica la necessità, per i decisori politici, di fornire gli agricoltori un livello adeguato di informazioni sugli attributi e le proprietà del digestato.*

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# Premise

The aim of my PhD project is to elicite farmers' willingness to pay (WTP) for digestate produced from the anaerobic fermentation of Mediterranean biomasses (citrus pulps, olive oil mixture, cattle manure, Opuntia and Italian sainfoin or Sorghum silage, etc.).
Currently, digestate is mainly used in those geographic areas where anaerobic plants are widespread (Manetto et al., 2020). In other areas like the Mediterranean basin, despite the high biomass potential available, the number of anaerobic digesters is very low and the use of digestate as soil conditioner is even more limited (Alyhesys, 2015; Chinnici et al., 2015b; Testa et al., 2016; Selvaggi et al., 2017). However, increasing the number of anaerobic digestion plants does not seem enough to promote the use of digestate as soil conditioner since its chemical-physical properties are yet little known among farmers.
Returning the soil to its natural cycle, or restoring the fertility of agricultural land through the recovery of nutrients through the production of digestate with the waste of the farm, allows to reduce the pollution from nitrates and phosphates with sustainable positive effects on the environment, on agricultural productivity and on the economy of the farms and of the local supply chain of the involved countries of the Mediterranean shore (Zuazo et al., 2008; Adubaker et al., 2012; Zecca et al., 2017;).

However, increasing the number of anaerobic digestion plants does not seem sufficient to promote the use of digestate as soil conditioner since its chemical-physical properties are still little known among farmers.

An important condition for widening the digestate market is informing potential users about its chemical/physical properties and its benefits for soil improvement. A lack of data on digestate characteristics could create significant uncertainty among farmers on those benefits. Such uncertainty could also have negative repercussions on the use of digestate as a conditioner and consequently on the willingness to pay for digestate notwithstanding the market potential. So, where digestate is little or completely unknown, informing farmers on its benefits might influence their WTP.

Our research focused on the Mediterranean area, where a new market for the digestate is desirable to determine new income opportunities for plant managers (Fabbri et al., 2010) and to reduce the typical dependence of the plants on public subsidies (Appel et al., 2016; Dahlin et al., 2017).

On these premises, the aim of this research is to evaluate if the level of farmer understanding about digestate attributes could influence the WTP for digestate. The research elicited farmers’ willingness to pay for the solid fraction of the digestate in the Mediterranean area, where new plants will be installed in the farms to try to reduce the gap with the Northern regions.

I wanted to test the commitment cost theory for a good not well known. In fact, real-world choices, however, are usually made in a dynamic setting. Committing a purchase decision under conditions of uncertainty might have a “Commitment Cost” (CC). In this study, I tested CC theory using a non-hypothetical experiment.

The activities that I have carried out during the three years of my doctorate are better specified below.

Bibliographic research was the fundamental activity of the first year of PhD course. Moreover, at the end of the first year, I attended the 2018 edition of the University of Bologna International Summer School on "Experimental Auctions" organized at the Free University of Bozen-Bolzano, on July 3-10, 2018 in Bolzano, Italy.

During the second year of PhD course, I attended a lot of courses about items that will be useful to improve my scientific profile. In particular, I attended several courses about mathematics and statistics, econometrics and agricultural policy applied to the agri-food economy, held as part of the advanced master's degree in economics and agricultural policy at the University of Naples Federico II, in Portici (Italy). Moreover, in June 2019, I attended 2 Summer Schools about:

- Spatial Statistics and Econometrics: organised at Parthenope University of Naples, from 3 to 7 June 2019, in Naples (Italy).

- Land Monitoring and Ecosystem Services Mapping and Assessment: organised at University of Naples Federico II, from 10 to 14 June 2019, in Portici (Italy).

So I've known a lot of econometrics model to improve my scientific profile and to better define my research activities.

During the third year, I focused my activities on data-analysis. I processed the data collected, as I could not carry out the period abroad due to contingent problems.

From the start to now, some papers were published, and others were submitted to reviews. Here is an updated list with exhaustive bibliography considering only the paper available on Scopus website:

1. Chinnici, G., Selvaggi, R., D'amico, M., & Pecorino, B. (2018). *Assessment of the potential energy supply and biomethane from anaerobic digestion of agro-food feedstocks in Sicily*. Renewable and Sustainable energy Reviews, 82: 6-13
2. Selvaggi, R., Valenti, F., Pappalardo, G., Rossi, L., Bozzetto, S., Pecorino, B., & Dale, B.E. (2018). *Sequential crops for food, energy, and economic development in rural areas: the case of Sicily*. Biofuels, Bioproducts & Biorefining, 12: 22-28
3. Selvaggi, R., Chinnici, G., & Pappalardo, G. (2018). *Estimating willingness to pay for digestate: evidence from an economic experiment from Sicilian farmers*. Quality – Access to Success 19 (S1): 489-493

4. Selvaggi, R., Verduci, M., & Pecorino, B. (2018). *Estimate of willingness to pay for Etna red wines: evaluation of the existence of an experiential component in purchase phase*. Quality – Access to Success 19 (S1): 494-499

5. Selvaggi, R., Pappalardo, G., Chinnici, G., & Fabbri, C. (2018). *Assessing land efficiency of biomethane industry: A case study of Sicily*. Energy Policy 119: 689-695

6. Valenti, F., Porto, S. M. C., Selvaggi, R., & Pecorino, B. (2018). *Evaluation of biomethane potential from by-products and agricultural residues co-digestion in southern Italy*. Journal of Environmental Management 223: 834-840

7. Pappalardo, G., Selvaggi, R., Bracco, S., Chinnici, G., & Pecorino, B. (2018). *Factors affecting purchasing process of digestate: evidence from an economic experiment on Sicilian farmers' willingness to pay*. Agricultural and Food Economics 6:16: 1-12

8. Pappalardo, G., Selvaggi, R., & Lusk, J.L. (2019). *Procedural invariance as a result of commitment costs: evidence from an economic experiment on farmers' willingness to pay for digestate*. Applied Economics Letters 26(15): 1243-1246

9. Ingrao, C., Selvaggi, R., Valenti, F., Matarazzo, A., Pecorino, B., & Arcidiacono, C. (2019). *Life cycle assessment of expanded clay granulate production using different fuels*. Resources, Conservation and Recycling 141: 398-409

10. Pappalardo, G., Selvaggi, R., Pecorino, B., Lee, Y.Li., & Nayga, R.M. (2019). *Assessing experiential augmentation*

*of the environment in the valuation of wine: Evidence from an economic experiment in Mt. Etna, Italy*. Psychol. Mark. 2019: 1-13

11. Selvaggi, R., Manetto, G., & Papa, R. (2019). *Sulla silage: first evaluation to produce sustainable bio-energy*. Quality-Access to Success, 20(S2)
12. Valenti, F., Porto, S. M. C., Selvaggi, R., & Pecorino, B. (2020). *Co-digestion of by-products and agricultural residues: A bioeconomy perspective for a Mediterranean feedstock mixture*. Science of the Total Environment 700, 134440
13. Manetto, G., Cerruto, E., Papa, R., Selvaggi, R., & Pecorino, B. (2020). *Performance evaluation of digestate spreading machines in vineyards and citrus orchards: preliminary trials*. Heliyon 6, e04257
14. Pappalardo, G., Chinnici, G., Selvaggi, R., & Pecorino, B. (2020). *Assessing the Effects of the Environment on Consumers' Evaluations for Wine*. Wine Economics and Policy 9(1): 31-42
15. Arena, E., Mazzaglia, A., Selvaggi, R., Pecorino, B., Fallico, B., Serranò, M., & Pappalardo, G. (2020). *Exploring Consumer's Propensity to Consume Insect-Based Foods. Empirical Evidence from a Study in Southern Italy*. Applied System Innovation 3(38), 10.3390/asi3030038

The published manuscript involved in this specific research project are identified with numbers 3, 5, 7 and 8.

Before starting the non-hypothetical experimental auction that is the more effective method within the methodologies of Revealed Preferences to elicit farmers' willingness to pay, I studied the context. In particular, the manuscript n. 5 concerns the potential availability of biomass and attests the possibility of building new plants in the Mediterranean area. So, potentially, Sicilian farmers will have digestate available for their farms. The remaining three papers involved in this research concern the estimation of willingness to pay, the search for attributes that influence it and the test of CC theory.

# 1. Introduction

## 1.1 Background information on biogas sector and digestate

Italy is second only to Germany in European biogas production from agriculture and the 4th in the world with over 1600 agricultural plants producing 2.5 Bn Nm$^3$/year of bio-methane (BM) (gross production including plant consumption) (Terna, 2020). According to Bozzetto et al. (2017), already by 2017, the agricultural biogas sector was guaranteeing 12,000 jobs, mostly created by numerous capital investments from other economic sectors.

In the last 20 years, Italian BM production has steadily increased, despite the consumption of gas has remained substantially stable, after a drop between 2008 and 2014 (Terna, 2018). From 2013 to 2018, Italian biogas grew to about 1447 MWel produced by 2009 plants of which about 80% were from the Northern regions and 20% from South-Central regions (Terna, 2020). Nearly all Italian biogas produces electricity even though recent policy incentives have been promoting the production of bio-methane from biogas (through the upgrading process) and so many plants are reconverting from electricity to bio-methane (Carfora et al., 2018).

Nevertheless, biogas production from dedicated crops like maize has significant environmental and socio-economical impacts, in terms of GHG emissions and because of the reduction in agricultural coverage for traditional food and feed production (Delzeit and Wolfgang, 2012; Britz and Delzeit, 2013; Lupp et al., 2014; Tamburini et al., 2020). Moreover, the use of digestate will improve biodiversity (Rana et al., 2016).

So, scientific research has sought to reduce the impact of biogas production on the environment and as a result Dale et al. (2016) proposed a new model of sustainable biogas production called Biogasdoneright® which reduces the impact of the bio-energy supply chain on the traditional food and animal supply chains. In particular, according to Biogasdoneright® principles, it is possible to produce "energy crops" as rotation crops, after food or feed crops; moreover, it is possible to produce bio-energy from the waste and by-products of the main agro-industrial chains.

So, applying Biogasdoneright® can improve farm sustainability both environmentally and economically and reduce the cultivation of energy-exclusive crops. Furthermore, Biogasdoneright® can increase farm incomes from agro-industrial biomasses insomuch as wastes becomes resources (Valli et al., 2017; Chinnici et al., 2018; Valenti et al., 2018 and 2020).

The agricultural biogas plants implementing Biogasdoneright® use 'integrated biomasses' as feedstocks, that are agricultural and agro-industrial by-products (eg. manure, straw, olive pomace, citrus pulp, whey and others).

Added to these biomasses, these plants use relatively small quantities of 'energy crops' cultivated in rotation or as second harvest crops, after traditional feed or food crops.

The Biogasdoneright® approach reduces the amount of traditional energy crops products (like maize silage) which used to feed anaerobic digesters, also exclusively. Now, renewable energy is guaranteed without reducing the agricultural lands for food and feed purposes (Abbess, 2015; Ammenberg and Roozbeh, 2017).

Even new European policies are promoting integrated biomass to produce advanced biofuels like bio-methane for the transport sector (Ahman, 2010). In 2012, the European Commission proposed a legislation to enhance the incentives for the best performing biofuels, and thereby to improve the greenhouse gas savings of the overall biofuel mix used in the EU, compared to fossil fuels. According to the European law on advanced biofuels (ILUC - Indirect Land Use Change), 'integrated biomass' has no direct or indirect impact on changing land use and allows for farms to improve their sustainability performance like for example by reducing greenhouse gasses and maintaining biodiversity.

The ILUC was proposed after scientific evidence on indirect land use change showed it impacted some biofuels: some types of biofuels, such as those from waste and residues, are much better than others in terms of their climate impact. These biofuels, like biomethane, which are typically more expensive to produce, do not lead to increasing food prices since they do not come from food crops.

Furthermore, exploiting biomass for energy by producing bio-methane can reinforce the economic competitivity of farms (Gibbins and Chalmers, 2008; IPCC, 2014; ECOFYS, 2016; Manetto et al., 2016).

The Biogasdoneright® approach has an even more interesting economic potential in the arid Mediterranean regions where traditional energy crops like maize cannot be grown. In this area, according to Selvaggi et al. (2018a and 2018b), traditional crops like Italian sainfoin (Hedysarum coronarium L.) or Sorghum spp grown as sequential crops after cereals or pasture. Furthermore, in the whole Mediterranean area, Prickly Pear (Opuntia) could be grown on marginal and abandoned lands.

Currently, the Southern Italian regions are well behind the rest of the country in terms of anaerobic digestion plants and agro-energy chain in general. The production potential of bio-methane in many parts of Southern Italy is undeveloped and even unknown despite being potentially very high (Pappalardo et al., 2018; Raimondo et al, 2018).

The production of renewable energy in a farm through an anaerobic digestion plant makes available a by-product, the digestate, which has excellent fertilizing characteristics as it has organic matter, elements of plant nutrition (N-P-K) and several micronutrients (ISPRA, 2010; Fabbri, 2013; Sogn et al., 2018).

Use of organic fertilizers contributes to maintaining and/or improving soil quality (Hati et al., 2006; Nkoa, 2014).

Moreover, the electricity from biogas can provide a larger share of clean electricity to power rising electrical mobility with clean energy (Röder, 2016). This would be facilitated with a biogas refinery, decentralized at the farm site, where digestate is used as fertilizer, in substitution or in addition to chemical fertilizers, connected to two different grids (Power and Electricity), and able to produce electricity and thermal energy, biofuels, food and feed in a flexible and programmable way to suit market conditions (SNAM, 2016).

Usually, digestate is defined as a part of the biogas chain that is an optimum example of circular economy: during the process, all the products are considered resources, and none are wastes (Selvaggi et al., 2018c).

The principle of the circular economy is based on an idea of reconstruction and involves changes in the structure of design and production (Chinnici et al., 2019). Usually, in a circular system, products retain their value for as long as possible. Each waste becomes a resource, and some resources can be taken from one production system and used in another production scheme without being discarded (Iraldi et al., 2015). Agroecological practices and circular economy approaches are at the core of a modern way of farming.

Circular agriculture means recovering the natural resources still circulating in the system rather than importing them from the outside (EEA Report, 2018). To respond to the current challenges, the agriculture needs to reinforce its innovation efforts, not only to produce sufficient healthful, safe, and affordable food for a growing population, but also to meet the goals of developing circular food chains, minimizing food waste, guaranteeing a fair distribution of the added value produced among the actors, using renewable energy and recycled nutrients in an efficient way (Zanoli et al., 2019).

Fundamental to closing the cycle, is the correct agronomic use of digestate which plays a key role in improving the environmental compatibility of anaerobic digestion with the surrounding environment both in terms of reducing costs and farmers' dependence on industrial fertilisers. Inspired by "biofuels done right" (Dale et al, 2010) which refers to integrating anaerobic digestion within the farm without reducing food or fertiliser production, 'biogas done right' term has been coined by Dale and his collaborators.

The environmental value of the digestate is greater if it is produced in plants that respect Biogasdoneright™ principles: the input biomasses for the plants are principally by-products from agro-industry activities (olive mill wastes, citrus pulps, whey, etc.) or agriculture one (livestock, poultry manure, cereal straw, etc.). In the Mediterranean area, the principle of 'biogas done right' has considerable potential to be applied efficiently. Currently, the scientific literature does not provide reliable estimates of the production potential of biogas via Biogasdoneright™ but such estimates should be done to plan the development of the biogas chain in the Mediterranean area.

In particular, in Mediterranean area anaerobic digestion can make use of at least three macro-categories of biomass: 1) waste and agricultural and agro-industrial by-products (e.g. olive residues, citrus pulp, whey) which are often treated as wastes; 2) silage from traditional Mediterranean crops in rotation or the second harvest of the main crops chosen according to irrigation availability; 3) silage or plant cuttings from typically Mediterranean bushy crops (e.g. *Prickly pear*, *Opuntia spp*) grown on marginal land.

Due to the 'biogas done right' principle, soils can be employed all year round, crop rotation can be diversified, chemical fertiliser consumption can be reduced by using digestate and renewable energy can be produced and used for the needs of the farm (Selvaggi et al., 2018b). So, an energy independent farm can be created with own fertilizers (digestate) and own energy (biogas for the production of electrical energy and biomethane for the tractors).

The optimal use of the digestate is crucial to improve agricultural production, and to reduce environmental impacts of the anaerobic digestion process (Tambone et al., 2009 and 2010; Mauceri et al., 2017).

The sustainable use of the digestate from anaerobic digestion plants can offer a low cost source of natural fertilizer with the reduction of pollution and increase of soil capacity, conservation and hydrologic stability and soil yields and at the same time with the decrease in erosion and soil salinity (Tambone et al., 2010; Alburquerque et al., 2012; Valenti et al., 2017a and 2017c).

Moreover, from an economic point of view, the digestate is an opportunity for the farmers both in terms of reducing costs and farmers' dependence on industrial fertilisers (Chinnici et al., 2015a; Cerruto et al, 2016; Selvaggi et al., 2018a).

Based on these facts, there is considerable scope to encourage and improve the utilization of digestate as a source to improve organic content in the soil, as well as consider agricultural co-products and by-products as a source and not anymore as a waste.

Digestate can play a role in addressing energy access challenges, providing opportunities for social and economic development in agricultural communities, contributing to local food security, improving the management of resources and agro-wastes, and providing environmental benefits.

Returning the soil to its natural cycle, or restoring the fertility of agricultural land through the recovery of nutrients through the production of digestate with the waste of the farm, allows to reduce the pollution from nitrates and phosphates with positive effects on the environment, on agricultural productivity and on the economy of the farms and of the local supply chain of the involved countries of the Mediterranean shore.

Digestate management strategies are planned not only for safe disposal but also to increase the value and marketability

(Logan and Visvanathan, 2019). In this regard, in several cases the simplest of post-digestion treatment technologies to facilitate the optimal economical and technical management and use of the digestate is the mechanical or physical separation in two fractions: a solid palatable fraction and a clarified liquid one (Provenzano et al., 2018).
Ordinary, the liquid fraction is used for the farms near the digesters. Local distribution systems are used to maximize the efficiency of use of nutrients and water. The distributions are in the same period of the irrigations, so it is possible to reduce water inputs (in some cases there are no irrigation inputs added to the digestate distribution). This liquid fraction is not transportable over long distances because it has a very low value in terms of nutrients for crops and, consequently, a very low economic value.
The solid fraction can be directly applied as fertilizer in agriculture or it can be composted or dried for intermediate storage and enhanced transportability.
Obviously, the use of digestate is common only where there are several anaerobic digesters, such as the Northern regions of Italy. In other areas, such as in the Mediterranean regions, even if there are a lot of available biomasses, there are only few digesters and the use of the digestate is still very limited (Manetto et al., 2016; Chinnici et al., 2018).
However, increasing the number of anaerobic digestion plants does not seem sufficient to promote the use of digestate

as soil conditioner since its chemical-physical properties are still little known among farmers.

The research focused on the Mediterranean area, where a new market for the digestate is desirable to determine new income opportunities for plant managers (Fabbri et al., 2010) and to reduce the typical dependence of the plants on public subsidies (Appel et al., 2016; Dahlin et al., 2017).

Furthermore, in view of the recent policy evolution that encourages the construction of anaerobic digestion plants for the final production of biomethane, it is predictable that the digestate in not yet manageable only at the farm level (actual ordinary condition). In fact, the dimension of the anaerobic digestion plant to produce biomethane is larger than the traditional plants for the production of electricity. The typical size of the Italian biogas plants ranges between 100 and 1,000 kWel/h. But, the new plants for the production of biomethane after the upgrading of the biogas will have big sizes, upper than 1,000 kWel, to justify the costs for the upgrade system. So, also the amount of digestate produced by the plants will be greater and it will be difficult to manage it only in the lands near the plants (ordinary condition). So, it will be necessary to sell the digestate daily produced by the plant and to have a market.

Currently, digestate is mainly used in those geographic areas where anaerobic digesters are widespread. In other areas like the Mediterranean basin, despite the high biomass potential available, the number of anaerobic digesters is very low and the use of digestate as soil conditioner is even more limited. However, increasing the number of anaerobic digestion plants does not seem sufficient to promote the use of digestate as soil conditioner since its chemical-physical properties are yet little known among farmers.

An important condition for widening the digestate market is informing potential users about its chemical/physical properties and its benefits for soil improvement. A lack of data on digestate characteristics could create significant uncertainty among farmers on those benefits. Such uncertainty could also have negative repercussions on the use of digestate as a conditioner and consequently on the willingness to pay (WTP) for digestate notwithstanding the market potential. So, where digestate is little or completely unknown, informing farmers on its benefits might influence their WTP. We have not investigated about a premium price for extra information, like done, for example, by Lombardi et al. (2018).

In conditions of uncertainty about the value of an asset, the estimate of the WTP as well as the identification of factors that influence the WTP could be affected by the possibility for potential consumers to delay the purchase to acquire future information on the same asset (Stigler, 1961). An interesting approach that economic theory suggests for estimating the WTP of a good little known among potential users is the theory of Commitment Costs.

In such conditions, economic theory suggests that WTP for a good does not solely depend on its intrinsic characteristics, but also on other factors such as a good's uncertainty level, the time available to make a purchase decision or the level of withdrawal from a purchase (Zhao and Kling 2000, 2001 and 2004). Some researchers have deduced that there is a commitment cost associated with a decision to purchase today which forgoes any future option to acquire additional information about a good. Consequently, commitment costs may have significant effects in estimating WTP and its consequent implications.

Despite numerous studies having highlighted the existence of commitment costs (e.g. Johannesson et al., 1999; Lusk, 2003; Corrigan, 2005; Corrigan et al., 2008; Kling et al., 2013; Bazzani et al., 2017), and their influence on the WTP, a little explored idea regards identifying the intrinsic characteristics or attributes of an asset which may influence WTP when there are commitment costs or which may contribute to arising them. Knowing little about an assets attributes may give rise to consumer uncertainty on the real value of an asset and consequent delay while further information is sought prior to purchase. In the case of digestate, knowing little about its chemical/physical properties could create farmer uncertainty about its use with consequent effect for his/her WTP (Jones et al., 2010) because of commitment costs.

The surveys were conducted in Sicily, in different areas where there are no anaerobic digestion plants and the farmers have no direct experience for the use of the digestate as soil improver. In fact, the areas where plants are already installed have not been considered in the current investigation, because there the farmers have own information (right or wrong) about digestate. Therefore, the effect of external information revealed by the interviewers could not be evaluated.

The detailed activities of the research will be better defined in the following chapters.

## 1.2 Research objective

Without need of mono-crops energy dedicated, having the possibility to produce energy (bio-methane, more specifically), advanced bio-fuel production in Southern Italy could stimulate investment and create new jobs. Moreover, in this new context the role of agriculture as one source of economic development in rural areas will be reinforced. So, the first phase of this research, I have evaluated the production potential of bio-methane in Southern Italy.

Since the diffusion of the anaerobic digestion plants and of the digestate in the areas involved in this project (Sicily) is limited not only for the low quantity of production but also for the lack of knowledge about the digestate's properties by farmers, this study aims mainly to investigate if farmers are willing to pay this "new" soil conditioner, and if the level of information that farmers have on digestate can affect their willingness to pay to buy it.

So, in the above mentioned context, the research wants to elicit farmers' willingness to pay for the solid fraction of the digestate in the Mediterranean area, where new plants will be installed in the farms to try to reduce the gap with the Northern regions.

Moreover, in the case of digestate, knowing little about its chemical/physical properties could create farmer uncertainty about its use with consequent repercussions for the WTP because of commitment costs. So, another aim of this research was to evaluate from the perspective of the theory of commitment costs, if the level of farmer understanding about digestate attributes could influence the WTP for digestate.

Starting from the above-mentioned purposes, this study aims to answer the following research questions (RQ):

RQ1 – Is there a production potential of biomasses in Sothern region to produce biomethane according to Biogasdoneright$^{TM}$ principles?

RQ2 – If digestate is available, how much are farmers willing to pay for solid fraction of the digestate?

RQ3 – Can organic soil conditioner attributes affect farmers' willingness to pay for digestate?

RQ4 - Is it possible to influence farmers' WTP by altering the number of bidding rounds and the expected amount of information to be gathered about the digestate (commitment cost theory)?

# 2. Materials and Methods

To answer the above research questions two researches have been conducted in the largest Mediterranean island, Sicily.

The first study conducted concerned the quantification of the agro-energetic potential of Sicily. It was an exploratory study, conducted on the basis of the consultation of databases (ISTAT, different years; Animal Husbandry National Registry, different years).

In fact, before participating in the lessons of econometrics and behavioural economic analysis, at Portici, I did not know analytical methods to evaluate consumers and farmers preferences, in particular. After learning the correct methodology and after having established the availability of biomass and the Sicilian productive potential in terms of energy and digestate, the second phase of the research was started.

The interviews took place in various Sicilian rural areas such as to involve farms with varying crops and different agricultural systems. Sicilian farmers (owners or managers) were interviewed all of whom are involved in decision making regarding farm machinery purchase. They were recruited with the help of local agricultural unions and some Sicilian agricultural cooperatives, from different areas where there are no anaerobic digestion plants. So the interviewed farmers did not have direct experience for the use of the digestate as soil improver. In fact, the areas where plants are already installed have not been considered in the investigation, because there the farmers have own information (right or wrong, but asymmetric as defined by Lofgren et al., 2008) about digestate. Therefore, the effect of external information revealed by the interviewers could not be evaluated.

Because there was no specific literature data on the WTP for digestate in this location, prior to the “official research”, preliminary surveys were carried out, on a group of farmers, with the aim of working out the minimum sample size of farmers to interview – i.e., the number of farmers to include in each experimental treatment. So, a pre-test was carried out on a sample of 60 Sicilian farmers in four different sessions corresponding to our main treatment effects. Using these data, we found a standard deviation of 5.12 and using a critical effect size of 1.34 (based on differences in means across sessions), we calculated the need of sample size of 56 subjects per treatment to attain 80% power. So, we had an adequate sample size to rely on large sample results.

The detailed activities of the research will be better defined in the following chapters.

## 2.1 Experimental Auction

### *2.1.1 Theoretical framework*

Farmers' willingness to pay for digestate has been estimated through "experimental auction" (EA) techniques in which the bidding products will be "digestate".

Experiments serve a vital role as a source of data that otherwise is prohibitive or difficult to acquire, as well as being a platform to test theoretical constructs. In the field of agricultural economics, where there is an acute need for accurate measurements of consumers' product valuations and behaviours in purchase situations (Baumgartner and Steenkamp, 1996), a sizable toolbox of value elicitation mechanisms has emerged.

Among these alternatives, experimental auctions and non-hypothetical choice experiments have rapidly been adopted in research due to their attractive theoretical properties and evidence of their external validity (Rousu, 2005).

The word auction is derived from the Latin "augere" and it means "to increase". In economic theory, an auction may refer to any mechanism or set of trading rules for exchange.

The Experimental Auction is defined as a method:

- ✓ to elicit "homegrown" values for goods (as opposed to "induced" values);
- ✓ that provides incentives for individuals to truthfully reveal their values and imposes a cost for non-truthful (or inaccurate) value revelation;

- ✓ where individuals bid against others in an active market where, in a WTP auction, the highest bidder(s) win the good and actually pay the market price.

The popularity of this method is due to its ability to simulate a real market situation where a consumer can make the decision to buy and actually pay for the product, thus offering to participants real products and allowing for exchange of real money. For this reason, experimental auctions tend to provide researchers with more accurate WTP values than hypothetical value elicitation methods.

Alfnes and Rickertsen (2003) suggested three core motivations to explain the popularity of the EA protocol:

1) the use of incentive-compatible mechanisms, so participants have real economic incentives to reveal their preferences, truthfully avoiding the hypothetical bias problem (List & Gallet, 2001).
2) strong innovation developed by the food industry in recent years and the continuous launch of new products. As a result, knowledge of consumer preferences and their determinants becomes the starting point for developing innovative products with true added value (Grunert, 2002; Steenkamp & van Trijp, 1996).
3) increasing consumer concerns over the safety and wholesomeness of food, related to new process technologies adopted in food production, such as the use of genetic modification, nanotechnologies, and food irradiation.

Unlike surveys and focus groups, participants in the EA make decisions that have true financial impacts (Gallet & List, 2003).
EA could be used in a hypothetical manner (i.e., not involving real money and real transactions), but usually, EA are non-hypothetical, because in the "research market" there are real products and real money. So the hypothetical bias refers to differences in response between settings in which the consequences are hypothetical or real (Harrison & Rutström, 2008) is avoided. In fact, in hypothetical settings participants do not put enough cognitive effort into the elicitation tasks and do not have an incentive to reveal their true values.
Many studies have found that when individuals are not incentivized with an economic commitment, they tend to reveal values for a good that might be greater than the price they would actually pay; i.e., people tend to overstate their actual WTP in hypothetical situations (List & Gallet, 2001).
Moreover, EA are incentive-compatible or incentive-aligned: products must be sold and it must be in the best interest of the participants to reveal their true preferences (Gallet and List, 2003). As defined by Harrison (2006), a mechanism is incentive-compatible when its rules provide participants with incentives to reveal their preferences truthfully and fully. In other words, the weakly-dominant strategy for every participant is to revel his/her true preference, as no strategic consideration can help anyone achieve better outcomes than the truth. A valuation mechanism is incentive-compatible if

every participant can achieve the best outcome to him/herself by truthfully revealing his/her preference, regardless of what others do. Strategic considerations cannot help anyone achieve better outcomes than the truth.

Lusk and Schoroder (2007) defined that a valuation method can be considered as incentive compatible when it "separates what people say from what they pay".

Auction winners pay for and receive the product, just as they would in the market place.

Hence, EA exploit the fact that these consumer decisions reveal preferences for goods, in both market and nonmarket contexts.

EA are designed to be incentive compatible, meaning that they induce each bidder to submit a bid that sincerely reflects his or her value for one unit of the good(s) being auctioned (Lusk and Shogren, 2006).

Formally, in the case of EA the procedure is incentive compatible if the individual has an incentive to submit a bid ($b_i$) that is equal to his or her own value ($v_i$) of the good ($b_i = v_i$).

Bidding true value yields a payoff at least as great as the payoff from all other strategies no matter what bidding strategies other rivals pursue (Lusk, Alexander, & Rousu, 2007).

Subjects payoff is an amount equal to:

$$v_i - p^* \text{ if } b_i > p^* \quad \text{and}$$
$$0 \qquad \text{if } b_i \leq p^*$$

Where $v_i$ is participant *i*'s induced value, $b_i$ is participant *i*'s bid, and $p^*$ is the market price.
In an incentive compatible auction, incentives for truthful bidding differ for relatively high and low value individuals. As such, some thought must be given regarding which type of individual is of primary interest for the study at hand. Our analysis indicates that when interest is on the top end of the demand curve (i.e., high-value individuals), a second-price auction is likely to provide accurate bids; a finding which does not depend on assumptions regarding the distribution of bidders' values. Thus, if marketers are interested in accurately identifying a market segment with high preferences for a new product, the second-price auction may be preferable.
According to Shogren et al. (2001), second-price auctions are designed to induce people to reveal their private preferences for a good. Laboratory evidence advises that while these auctions do a reasonable job on aggregate, they fall short at the individual level, especially for bidders who are off-margin of the market-clearing price.
The most relevant advantages linked to the use of experimental auction procedures are listed below:

- ✓ one obtains a bid (WTP value) from each individual precluding the need to make parametric assumptions about the shape of the market demand curve;
- ✓ involvels the exchange of real goods and real money;

- ✓ modelling determinants of WTP is straightforward given the continuos nature of the dependent variable;
- ✓ subjects can incorporate feedback from the experimental market into their bids as they might in an actual market setting;
- ✓ there is a wealth of theoretical literature on auctions that can aid researchers in designing appropriate experiments.

Moreover, EA allow researchers to:

- ✓ control possible deviations from true values and the strategic behaviour of participants;
- ✓ obtain individual WTP (enabling parametric assumptions regarding the form of the demand curves of the market);
- ✓ model the determinants of the participants' WTP:
- ✓ and (in some mechanisms) enable participants to incorporate the information feedback from the EA regarding their bids (Lusk and Hudson, 2004).

The experimental auction method was used given that it is now an established method in product valuation research, even if there are the limits listed below for this method:

1. First, the problem of field-price censoring arises from the availability of immediate substitutes to the chosen laboratory commodity. A rational subject will not agree to obtain the same commodity in an experiment at a price that he perceives can be beaten outside the lab with sufficiently high probability. This implies that elicited values will be censored

at the perceived extra-laboratory price of the good. Il partecipante si porta nell'asta la conoscenza dei prezzi dei prodotti sostitutivi e quindi il prezzo di riserva per il prodotto in oggetto è condizionato.
2. Beliefs about field prices are affiliated; that is, when it is rational for one subject's beliefs to be positively responsive to the beliefs of subjects whose information differs from his. In such cases respondents may revise their valuations after observing the stated values of other respondents.
3. Affiliated beliefs about the quality of the laboratory commodity itself. Subjects who are uncertain about the characteristics of the commodity might rationally infer information about those characteristics from observing other respondents' stated values.
Moreover, a lot of biases could be influence the results of an experimental auction procedure. The major cognitive biases are below listed, subdivided in 7 categories:
CATEGORY 1 – Recruitment

- Reciprocity effect: participants would like to return the kindness of the researchers;
- Windfall effect: participants use the money as if it were extra to throw away (without giving it value);
- Panel size effect: the number of participants affects the offers;
- Sampling bias: non-random sampling due to time/day.

CATEGORY 2 – Training and practice

- Training effect: participants do not fully understand the functioning of the EA;
- Trial winner effect: the winners of the test auctions behave in a non-rational way in the main auction.

CATEGORY 3 – Number of rounds/products

- Multiple-bid effect: first round winners offer less in subsequent rounds (decrease in marginal utility);
- Multiple-good valuation effect: the number of products offered affects the ratings;
- Product order effect: the order of presentation of the products affects the evaluations.

CATEGORY 4 – Information provided

- Confirmation bias: preference towards information that confirms preconceptions;
- Conflicting product information effects: negative information generally predominates over positive information;
- Information order effect: the order of presentation of the information affects the assessments. The information presented first is remembered more (primacy effect) or less (recency effect). The second case prevails.

CATEGORY 5 – Bidding procedures

- Anchoring bias - price posting: a reference price influences the offers;

- Price feedback: participants are influenced by the offers of others (market price information);
- Endowment effect - WTA versus WTP: gap between willingness to accept (WTA) and WTP, explained by Tversky's loss aversion and Kahneman's theory of reference-dependent preferences; this effect was defined also by Kahneman et al. (1991), according to which people place a higher value on what they possess than they place on the same things when they do not possess them;
- Methodological bias: all EA mechanisms have specific issues.

CATEGORY 6 – Social context

- Social desirability bias & warm glow: participants want to make a good impression on others. Utility from giving or saying to give;
- Cuoriosity bias: participants only offer to try the new product;
- Top-dog effect: participants want to win, regardless of interest in the product;
- False consensus effect: consumers tend to think that they are behaving like others;
- Projection bias: the moment of the auction influences the WTP (i.e., hunger, thirst, fatigue and other).

CATEGORY 7 – Practical Problems

- Students as partecipants (1): students are not always familiar with specific products;
- Students as partecipants (2): students just want to take the money and run away;
- Students as partecipants (3): students don't always understand the mechanism (but they don't say it);
- Discount effect: participants, due to the limited offer and from the time of purchase not chosen by them, discount the products.

The experimental design was drafted to control background variability. So, the systematic effects of treatments can be observed, and confounding factors can be deleted. Generally, three are the basic principles (in order of their importance) to control background variability:

1. Control by matching: matching is only possible on observable characteristics and perfect matching is not always possible. Furthermore, matching inherently limits generalizability by removing possibly desired variation.
2. Control by randomization: randomization controls for the effects of all characteristics (observable or non-observable, known or unknown). Random assignment is not assignment with no particular rule. It is a purposeful process. Researcher shall ensure that each treatment will have an equal chance of being tested in any particular individual.
3. Control by statistical adjustment. It is a form of pseudo-matching. It uses statistical relations to simulate matching (propensity score matching). Statistical control is the weakest

of the three experimental design principles because its validity depends on knowing a statistical model for responses.

### 2.1.2 Procedure

From April to June 2017, 223 Sicilian farmers (owners or managers) were interviewed all of whom are involved in decision making regarding farm machinery purchase. Farmers participated in a non-hypothetical experimental auction (Lusk and Shogren, 2007; Pappalardo et al., 2016; Pappalardo and Lusk, 2016; Wongprawmas et al, 2016; Selvaggi et al., 2018c and 2018d). This type of experiment offers the advantage of providing an incentive for participants to truly reveal their preferences.

In the first step of the study, we recruited farmers for the experimental auctions and, at the same time, farmers were asked questions on knowledge of soil conditioners, digestate and demographic information. A specific consent form was given to every participant, according to the model attached (Appendix A).

After, when the farmers were asked about their willingness to participate in the survey, the interviewers asked some screening questions: 1) Were they owners or managers of the farm? 2) Were they responsible for acquiring farm machinery? 3) Did they use soil conditioners on the farm or would they be interested in doing so? If all the answers were affirmative, those farmers were invited to take part in the survey by meeting up one day at a predetermined time to be interviewed using the experimental auction method. If even in this case they answered affirmatively, the farmers were invited to fill out a questionnaire asking for some socio-demographic data. The complete questionnaire used for the research is in attachment in appendix (Appendix B).

In the second step of the study, a second price experimental auction mechanism (Vickrey auction) (Vickrey, 1961) was designed to elicit WTP for the digestate, and we couple these data with answers from a set of *Best-Worst* (BW) scaling questions that provide a score of the relative importance of various soil conditioners' attributes. By combining the two approaches, we have provided an estimate of attributes that can affect WTP for digestate. The complete protocol of the experimental auction procedure is in attachment in appendix (Appendix C).

The farmers in the experimental auction were each assigned a personal ID number and given a bag of bidding tickets so as to be able to bid anonymously during the auction experiment.

Once the farmers were all seated, the coordinator explained that the experimental auction consisted of various rounds and that each participant would make various bids to acquire digestate. With all the rounds over, one round would randomly be selected to reveal the auction winner and the second highest bid which would represent the market price.

The number of rounds depended on the experiment treatment the farmer had been allocated to but in never treatment, after each round, data on the highest bid and the second highest bid which determined the sale price were provided.

Prior to the experimental auction with the digestate, five test rounds were carried out with an anonymous test product (a 500-gram packet of spaghetti). This auction was only to familiarise the bidders on the protocol and to reduce the *training effect* bias.

In the real auction, the bidding was for a ton of digestate.

The auction winner received a coupon for a ton of solid digestate at market price (second price of the auction) from a digestate producer. The farmers' bids did not include transport costs from the producer to the auction winner's farm.

In a second-price auction, a person's weakly dominant strategy is to reveal their true WTP (Vickrey, 1961). In the WTP case, overbidding increases the likelihood that a subject will have to pay more for the good than desired, underbidding increases the chance that he will not win what he could have won if he had stated his true preferences. In the WTP treatment for each trial in each stage, bidders were asked to record, privately and independently, the maximum he or she was willing to pay for the goods on a recording sheet. At the end of the auction, the auction leader or auctioneer posted posted the identification number of the highest bidder and the market-clearing price — the second highest bid — on the blackboard as public information.

To incentivise their participation in the survey, each participant was given €10 of food products.

The experimental design was set up to give farmers different waiting times to decide on their WTP and different levels of information on the attributes of digestate.

To this purpose, I utilized four experimental treatments:

- ✓ T1 - *control group* (56 members): the experimental auction had only one round and its members were only provided with basic information on digestate and shown a sample of digestate. No information on the attributes of digestate was provided to the participants;
- ✓ T2 (55 members): the experimental auction had 5 rounds and bidders were given the same basic information on digestate as in the previous group and shown the same sample of digestate. No information on the attributes of digestate was provided to the participants;
- ✓ T3 (56 members): the experimental auction had 10 rounds and the bidders were given the same basic information as in the 2 previous groups as well as the same sample of digestate;

- ✓ T4 (56 members): the experimental auction had 10 rounds, but bidders were told that after the first five rounds they would receive additional information on digestate regarding the attributes of it. The bidders made their first five bids on the basic information received in the 3 previous treatments. Subsequently, bidders made 5 more bids having received the additional digestate information. These information were related to the following 8 attributes selected by main literature on the topic (e.g. Dahlin et al., 2015; Hou et al., 2017): Organic origin, Soil fertility, Environmental sustainability, Local production, Safety, Price, Natural product, Microbial activity.

After the auction, for the above digestate's attributes we also assessed the relative importance assigned by farmers by using the Best-Worst scaling approach, which was originally introduced by Finn and Louviere (1992) and was further developed by Marley and Louviere (2005). Respondents made several repeated choices for the Best-Worst scale evaluation, where the set of items varies across questions. Respondents were shown a set of items and were asked to indicate which was the best and which was the worst (or, in this case, which was most and least important).

The items used in BW questions were soil conditioners' attributes selected by main literature on the topic. They are better defined in the appendix (Appendix D).

# 3. Collection of the published papers, related to the PhD research project

- Selvaggi, R., Pappalardo, G., Chinnici G., & Fabbri, C.I., (2018). *Assessing land efficiency of biomethane industry: A case study of Sicily*. Energy Policy, 119:689-695. doi.org/10.1016/j.enpol.2018.04.039

- Selvaggi, R., Chinnici G., & Pappalardo, G., (2018). *Estimating willingness to pay for digestate: evidence from an economic experiment from Sicilian farmers*. Quality Access to Success, 19(S1):489-493

- Pappalardo, G., Selvaggi, R., Bracco, S., Chinnici, G., & Pecorino, B., (2018). *Factors affecting purchasing process of digestate: evidence from an economic experiment on Sicilian farmers' willingness to pay*. Agricultural and Food Economics, 6:16. doi.org/10.1186/s40100-018-0111-7

- Pappalardo, G., Selvaggi, R., & Lusk, J.L., (2019). *Procedural Invariance as a Result of Commitment Costs: Evidence from an economic experiment on farmers' willingness to pay for digestate*. Applied Economics Letters, 26(15):1243-1246 doi.org/10.1080/13504851.2018.1545070

*Energy Policy (2018) 119:689-695*
http://doi.org/10.1016/j.enpol.2018.04.039

# Assessing land efficiency of biomethane industry: A case study of Sicily

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## Abstract

*Recent estimates show that the potential for biomethane production in Italy for 2030 is about 8 Bn Nm$^3$/year, initially by upgrading the biogas produced by anaerobic digestion. We derive the 'Land Efficiency' of Biomethane in accordance with the Biogasdoneright® principles in Sicily (Italy), from the standard formula to determine the 'First Crop Land Requirement'.*

*The results were achieved using large proportions of 'integration biomasses'. The concept of Land Efficiency is verified because the first constituent of the formula (land efficiency) is much higher than the second one (biomethane yield of monocrops).*

*The outcome of this study indicates clearly that 'integration biomasses' in the Sicilian context are among those which produce advanced biofuels. All by-products and wastes from the agrifood sector are necessary to produce about 562*

*million Nm3/year of biomethane in Sicily for 2030 (about 8% of the Italian one), allocating only 28,000 ha for the monocrops for the anaerobic digesters.*

**Keywords**: Biomethane, Biogasdoneright®, Energy management, Land efficiency, Second harvest

## 1. Background information

Italian Biogas production is the third largest in the world after China and Germany with more than 1,400 biogas plants at farm level producing over 2.5Bn $Nm^3$ [1]/year of Biomethane (BM) thus far equivalent to combined heat and power (CHP) systems and creating 12,000 direct, permanent and qualified jobs in the last five years (Bozzetto et al., 2017). In particular, from 2013 to 2016, Italian biogas sector has grown until to reach an installed capacity of about 1,000 $MW_{el}$, of which 85% in the northern regions and the remaining 15% distributed between the central and southern regions (GSE, 2017). Thanks to feed in tariff (a public subside), all the biogas produced in Italy has been used to produce electricity;

[1] $Nm^3$: *Normal cubic metres* is the unit of measure used for the gas in "normal conditions", i.e. in relation to atmospheric pressure and at a temperature of 0 °C.

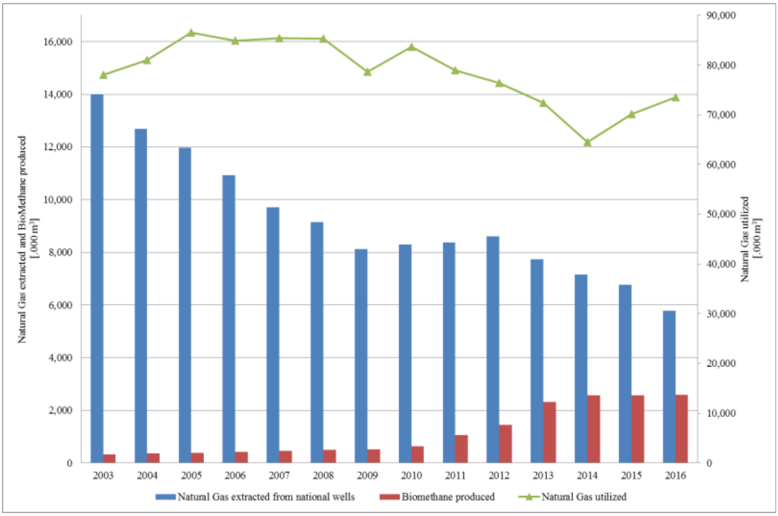
recently new incentive policies are encouraging biomethane production from biogas through the so-called "upgrading process" (Carfora et al., 2018).

In Sicily, currently, there are only 4 operative biogas plants at farm level, but there are 3 additional authorized plants (not yet realized) for advanced Biomethane production (not from food crops). Actually, the biogas plants produce electricity for the grids, for a total of 2 MWel every hour.

As regards the production of biomethane, as showed in the next figure (Figure 1), its production has increased and stabilized since 2013. Instead, the quantity of Natural Gas extracted from national wells was decreased, according to the recent political guidelines. In 2016, Biomethane produced was 44.5% of the national gas wells.

In the same figure, the processed data show a recovery in the trend of gas consumption, after a period of decline (from 2008 to 2014).

**Figure 1 – Trend of Biomethane produced and Natural Gas extracted and utilized**




(Source: C.R.P.A. elaboration on TERNA data)

In this context, Italian biogas has developed so-called 'Biogasdoneright®' platform technologies (Dale et al., 2016) which have completely restructured farming activities around anaerobic digestion plants and strengthened the ability of farms to produce food and feed as well as renewable energy (Manetto et al., 2016).

These results have been achieved by using large proportions of so-called 'integration biomasses' which are the waste and by-products often considered environmental problems (livestock effluents, agricultural by-products, food processing waste), and crops harvested from agricultural land held bare during the year (double cropping) or annually (set aside 'maggese[2] ').

The use of integration biomasses will make it possible to reduce the use of energy crops and, therefore, ensure the supply for food, feed and energy chain.

At the European level, these 'integration biomasses' whether obtained from food, feed crops or other, are the biomasses that should be used in the production of advanced biofuels, since they do not cause any indirect land use change impacts (ILUC), but allow farms to improve their sustainability performance regarding greenhouse gas (GHG) emissions and biodiversity compared to conventional farming, and ultimately they strengthen the economic competitiveness of the farms (Gibbins and Chalmers, 2008; Ecofys, 2016; IPCC, 2014).

The agronomic practices of Biogasdoneright® require substantial modification of current farming practices:

- It requires a greater recycling of livestock effluents and by-products;

[2] Maggese is the Italian word to indicate the lands with natural grass cover included in the rotation with principal crops (i.e. durum wheat), a common practice to reduce soil organic matter losses in Mediterranean climates.

- It increase the cultivation of energy crops for the production of silage, even when there is no local requirement from livestock industry by maintaining all year ground cover and thereby greatly reducing farmland GHG emissions and improving photosynthesis;

- It increases the number of crop rotations thereby increasing biodiversity;

- It improves soil fertility by increasing soil biomass (roots, plant parts) and restoring organic fertilization via biogas digestate or biofertilizer;

- It reduces the cost of chemical fertilizers, the cost input for production and diversifies output markets.

In a nutshell, Biogasdoneright farm feedstocks not only obviate monocrop to bioenergy systems thereby lowering food production but also improve farm sustainability from an environmental and economic point of view and ultimately augment Food Security and the economic profitability of biomass production (Valli et al., 2017; Valenti et al., 2017b and 2017d; Chinnici et al., 2018).

In a nutshell, the application of the Biogasdoneright® concept improve farm sustainability from an environmental and economic point of view, but also reduce the cultivation of lands for energy use. Moreover, this approach of production increase the economic profitability of biomass produced by farms and agro-industrial systems (Valli et al., 2017; Valenti et al., 2017c; Chinnici et al., 2018).

From these simple concepts, five years ago the Italian Biogas sector developed a roadmap targeting 8Bn Nm3/year of BM by steadily increasing their use (Bozzetto et al., 2017). Sicily is one of the Italian regions falling short of the target, but due to its strong agriculture sector and its geography (Mediterranean climate, desertification of the farmland, agro food productions, etc.) it holds about 8% of the national potential for 2030 corresponding to about 562M Nm3/year which includes about 40M Nm3/year of biomethane from Municipal Organic Waste (MOW).

This target can be achieved with:

- 20% of BM obtained from monocrops cultivated in areas that are becoming economically marginalized in today's market conditions;

- 80% via so-called integration biomass like livestock effluents, agro-waste and ground-cover crops which without the additional demand created by anaerobic digestion plants would not be produced.

This study, from our perspective, clearly concludes that 'integration biomass' is to all intents and purposes among those allowed for the production of advanced biofuels as clarified in Annex IX of the new (Renewable Energy Directive) RED 2015/1513. Specifically, for the Mediterranean area and Sicily, the ground-cover crops highlighted in our Plan (i.e. Italian sainfoin, Sorghum spp, cereals and pulse mixtures) can be classified as advanced biofuel biomass (see Annex [3]), when inserted in a rotation before or after a cash crop for the market or stable (i.e. durum wheat) (Selvaggi et al., 2018).

With clear legislation on the biomass suitable for advanced biofuels, Italy with more than 1 billion $Nm^3$/year as compressed natural gas (CNG) or liquid natural gas (LNG) fuel (8 billion $Nm^3$/year forecasts for 2030) and more than 1,200 outlets already has a consolidated market for utilising biomethane as road transportation fuel. It must be noted that in this case BM can not only reduce exhaust emissions compared to petrol and diesel, but according to Biogasdoneright® principles its production will also lead to a stark reduction in agricultural and agroindustrial GHG

[3] 'non food cellulosic material' means feedstocks mainly composed of cellulose and hemicellulose, and having a lower lignin content than ligno cellulosic material; it includes food and feed crop residues (such as straw, stover, husks and shells), grassy energy crops with a low starch content (such as ryegrass, switchgrass, miscanthus, giant cane and cover crops before and after main crops), industrial residues (including from food and feed crops after vegetal oils, sugars, starches and protein have been extracted), and material from biowaste.

emissions, will improve biodiversity and farm economies thereby contributing to securing food safety for the EU (Rana et al., 2016).

Last but not least, fostering advanced biomass biofuels and avoiding mono-cultures will trigger investments for €1.2-1.5Bn and create 3,000-3,500 directly qualified jobs in Sicily until 2030 (Althesys, 2015). Such a development plan, along with other potential species for biomass utilization (e.g. Giant Reed), can contribute to reversing the tide and make Sicilian agriculture the root of economic development in rural areas with new markets for farms (Chinnici et al., 2015b; Sgroi et al., 2015; Testa et al., 2016), especially nowadays when many agro-industrial systems are getting economically marginalized which has lead to the closure of farms and processing industries. So, biogas plants can be seen as real refineries (biogas biorefineries) that add value to different feedstocks for energy, biomaterials and biofertilizers (Abbess, 2015).

Italy has already adopted a legal framework for the production of at least 2% of advanced biofuels up to 2020: the Biomethane produced with the 'integration biomass' can therefore play a key role in reaching this target, according to the new Renewable Energy Directive (RED II) that will enter into effect on January 1, 2021.

It establishes a set of policy measures for the production and promotion of renewable energy in EU. In particular, RED II sets out measures to achieve a 27% renewable energy share from energy consumed by the electricity, heating and cooling, and transportation sectors by 2030. It defines the standards for the production of all biofuels consumed in EU and ensure that they are produced in a sustainable and environmentally friendly manner. All the assumption in this manuscript are in accordance with these political guidelines.

## 2. Land Efficiency

The term 'land efficiency' in the bio-energy context means the total quantity of primary energy obtainable from a hectare of agricultural land used to produce biomass for bioenergy (rather than feed or food products).

Land efficiency is calculated from the following formula (freely adapted and adjusted from the study of Lynd et al., 2007):

$$FCLR\ (ha) = (A - I)/C * 1/P$$

Where:

**FCLR** (First crop land requirement): Land needed (ha) of first crop harvest to reach the desired yearly biomethane production

**A**: Total production of biomethane ($Nm^3$/year)
**I**: Production of Biomethane generated via Integration Biomass ($Nm^3$/year)
**C**: Biomethane yield as first crop biomass (Mais) ($Nm^3$ $BioCH_4$/ton Dry Matter)
**P**: First crop yield (t/ha Dry Matter)
From this formula, we derive that biomethane 'Land Efficiency' according to Biogasdoneright principles is given by total annual Biomethane production (factor A in the formula, $Nm^3$/year) divided by the Utilised Agriculture Area (UAA) used for the first crop harvest (the FCLR, ha).

$$\text{LAND EFFICIENCYBiomethane} = A/FCLR \ (m^3\ CH_4/ha) >> C*P\ (m^3\ CH_4/ha)$$

It is clear that 'I = integration biomass' is the key factor [4] in the principal formula. From now to 2030, as integration biomass steadily increases with a corresponding decline in first harvest crops, biomethane Land Efficiency is going to increase over time.

In table 1 below, the formula constituents are detailed as is the potential development of Biomethane in Sicily up to 2030

[4] The development of "Integration Biomass" is the key aspect of redesign the farming activities around the anaerobic digesters. Thanks to the anaerobic digestion is possible to lower GHGs emissions from conventional farming, increasing productivity, achieve a real "ecological agricultural intensification" and store carbon in the soil.

from livestock, ground-cover, perennial crops and agricultural byproducts.

**Table 1 – Potential development of agricultural and livestock biomethane in Sicily until 2030**

| Member of the formula | Description | Unit | Value |
|---|---|---|---|
| A | Target 2030 | (thousand $Nm^3$/year) | 562,000 |
| I | Integration biomass Biomethane | (thousand $Nm^3$/year) | 437,680 |
| | *- From cover and perennial crops* | *(thousand $Nm^3$/year)* | *351,540* |
| | *- From Byproducts and agrowastes* | *(thousand $Nm^3$/year)* | *86,140* |
| C | Monocrop Biomethane yield | ($Nm^3$/t) | 111 |
| P | Monocrop yield | (t/ha) | 40 |
| **FCLR** | UAA Monocrop | (ha) | 28,000 |
| | **Elaboration** | | |
| **(A-I)** | Monocrop Biomethane | (thousand $Nm^3$/year) | 124,320 |
| **(A/FCLR)** | LAND EFFICIENCY | ($Nm^3$/ha) | 20,071 |
| **(C*P)** | Monocrop yield Biomethane | ($Nm^3$/ha) | 4,440 |

Our idea is a production target for Sicilian biomethane in 2030 of 0.562Bn $Nm^3$ which would be 7% of the national target for 2030 (8 billion Nm3).

The concept of Land Efficiency is verified because the first constituent of the formula (A/FCLR) is much higher than the second (C*P).

Below, we will provide more details about:

- the reasons behind the decision to allocate 28,000 hectares to biomass production for anaerobic digestion (AD) via monocrops;

- the quantities and types of integration biomass that can be reasonably estimated for AD up to 2030, why they will not create any ILUC effect and why they will strengthen the environmental and economic position of Sicilian agriculture.

## 2.1 INTEGRATION BIOMASS

Most Sicilian biomethane's (80%) production target will be achieved with the integration biomass which qualifies for the advanced biofuel scheme as described in annex IX of the new RED directive 2015/1513.

Integration biomass can be subdivided into two main categories:

a) agricultural and agro-industrial by-products and waste;
b) biomass from ground-cover crops;
c) Municipal organic waste.

### *a. Agricultural and agro-industrial by-products and waste*

Before analyzing in detail the residual biomass from other production processes, it must be pointed out that everything stated above is possible, feasible and sustainable over time due to the flexibility of AD. Other more technologically complex biomass-to-energy industries have failed to solve adaptability issues and achieve technological maturity even on a small-scale where anaerobic digestion is still applicable.

Biogas is indeed a winning technology when it comes to recovering energy from residual biomass given it not only handles very diverse inputs but also biomass blends as part of the so called AD 'diet'. Moreover, biogas is also an open source technology with all the ensuing benefits.

'Biomass co-digestion' is the best way to obtain both high energy yields and limit the critical issues arising from the use of non-uniform individual matrices which are irregular over time.

The types of 'residual biomass' applicable to anaerobic digestion are very varied, and can be grouped into three major categories:

- livestock effluent;
- crop residues;

- agricultural/agro-industrial waste and by-products.

*Livestock effluent*

Livestock effluent was estimated from the number of animals bred (National Animal Husbandry Registry, 2016) and their average weight by unit production ratio relating to animal species, the breed at the growth stage, and the predominant stable layout for each category. It is worth noting that the calculation applied is the same as used in the technical standards for applying former Art. 38 of the Italian Legislative Decree 152/99 [5]. The different unit rates of manure production are the result of numerous analyses in the database of the Animal Production Research Centre laboratories (CRPA) and collected since the early 70s.

The species concerned are cattle and buffaloes, pigs and poultry which translates into a total production of nearly 5M tonnes of livestock effluent mostly cattle manure (over 4M tonnes).

The co-digestion of animal manure with other biomass is the most widespread practice, according to the census of agro-

[5] Now Legislative Decree 152/2006 at the national level: the DM 07.04.2006, recently replaced and augmented with digested by the recent Decree of 25 February 2016

livestock biogas plants conducted in 2013 (Fabbri, 2013), which actually photographed the national situation at the end of the three years of the Feed-rate incentive (2010-2012) (Chinnici et al., 2015a).

For the purposes of this study’s purview, it was assumed that the anaerobic digestion of manure would become an increasingly common practice by 2030 involving up to 90% of poultry manure (transport costs acceptable for high yields and high content of dry matter) while recoverable cattle manure is limited (10-20%) due to its being spread over pastures and due also to cow-calving.

The motivations behind these choices are the following:

- the mitigation of GHG emissions from the livestock industry coupled to AD are well known as is AD becaming the foundation on which to build a sustainable meat and dairy industry from an environmental, economic and social point of view. This would lead to further growth in AD coupled to livestock;

- the European and national regulatory framework are moving in this direction. Environmental policy is very clear; the economic support tools available to farmers (RDP 2014-2020) for improving competitiveness by lowering the carbon footprint per unit of product weight and in general reducing pollution by agriculture and the livestock industry (Lupp et al., 2014);

- the operating costs of disposing of livestock industry waste are growing, and so turning them from a cost to a profit by using them in digesters has become a prerequisite for modern, environmentally concerned farming.

*Crop residues*

Farming produces crop residues, plant parts not intended for human or animal consumption, such as stems, leaves and cobs which can produce energy. Each agricultural waste has been quantified using three essential parameters;

- total production for each herbaceous crop (average yields for the region - Source ISTAT 2010)

- relationship between the main product and by-product (different bibliographic sources)

- fraction or percentage of the residue or by-product already recycled or reused.

While taking into account any inherent calculation errors, Sicilian herbaceous crop residues have been estimated at around 800,000T, of which 500,000T are straw and stalks.

Furthermore it is estimated that about 20% of these crop residues (160,000T, or 30% of straw and stalks) can be converted to biogas (in addition to the amounts from manure). This is due to the expectation that where there is a digester, the use of bedding material (i.e., straw) on farms will increase; in the farms without digester, cattle manure cannot be used for energy purposes and the farmers reduce the content of bedding material for the animals to decrease the quantity of cattle manure (Selvaggi et al., 2017a). Therefore, AD can also lead to improving animal welfare in the livestock industry, through drier and cleaner litter.

*Agricultural and agroindustrial by-products*

This assessment was made on the production sectors generating regular good quality organic residues in significant quantities; in particular the manufacturing and processing industries for grapes, olives, citrus fruit, tomatos, meat and milk which generate the largest flows (Cerruto et al., 2016; Valenti et al., 2017a). For each sector listed, quantifying by-product flow was based on the following:

- raw material quantities inputed to the various production cycles (milk, tomatoes, grapes, olives). The sources used are the official ones, such as ISTAT, associations, Confindustria, Food Producers Organizations, etc.;

- Defining the 'waste units per unit weight of raw material input' coefficients.

It should be noted that the selected coefficients derive from a specific in-depth survey led by the CRPA (Research Centre on Animal Production) on the agro-industrial sector of the Emilia-Romagna region, where there is a high degree of integration in the supply chain.

The production ratios of the various by-products over the raw material input weight were measured by tests in over 30 food processing companies chosen as most representative for size and food type in Emilia Romagna.

The methodology to estimate manure and agro-industrial by-products was applied in the CRPA study on behalf of the Institute for Environmental Protection and Research (ISPRA) which led to the publication of the report 'Study on the use of biomass fuels and biomass waste for energy production' 111/2010 Report (ISPRA, 2010).

On the oil and citrus processing industries, an estimate was also made on the basis of specific research by the University of Catania (Valenti et al., 2017d).

After estimating the total flow of the most significant agro-industrial by-products, they concluded that 30-75% could be used in anaerobic digestion. However, recovery percentages closer to 100% by 2030 would be desirable.

It should be noted that this estimation included no milling by-products because its flow is difficult to determine. Moreover, they are usually destined for different applications (i.e. feed, confectionery industry) and traded as agricultural commodities.

### *2.1.1 Partial Results: summary of biomethane from different sources*

Based on quantitative estimates, the total contribution for 2030 of 'residual biomass' is just over 86 M Nm3 of biomethane/year as detailed in table 2 below.

Note that the estimate of total biogas potential from biomass residues as illustrated above was conducted by adopting precautionary criteria:

- based on data of converted raw materials for 2013-2015; variations over recent years were almost negligible;

- a specific average biomethane yield was assigned to each biomass calculated on real data, repeated, validated and used with a conservative approach (i.e. excluding unjustified peak values);

- food industry by-products (bakery or other) were not considered because they are difficult to quantify. Yet, they are readily available (not in significant quantities) and excellent for producing biomethane (because of low moisture and high degradable organic matter).

**Table 2 – Residual biomasses available in Sicily for AD and their potential biomethane production**

| | Total available, estimation [Million t FM/y] | Used for AD, estimation | Biomethane specific yield [$Nm^3/t$ VS] | Biomethane specific yield [$Nm^3/t$ FM] | Biomethane potential [Thousand $Nm^3/y$] |
|---|---|---|---|---|---|
| **Livestock effluents** | **4.97** | **1.13** | | | **46,150** |
| - cattle liquid manure | 2.04 | 20% | 240 | 14.1 | 5,750 |
| - pig liquid manure | 0.10 | 50% | 300 | 9.7 | 474 |
| - poultry manure | 0.03 | 80% | 320 | 106.6 | 3,000 |
| - cattle manure | 2.66 | 20% | 212 | 38.3 | 20,360 |
| - layng hens manure | 0.14 | 80% | 300 | 150.0 | 16,570 |
| **Agrowastes - vegetables** | **0.78** | **0.43** | | | **18,888** |
| - olive pomace | 0.14 | 50% | 250 | 88.3 | 5,990 |
| - oil mill waste water | 0.18 | 50% | 475 | 16.6 | 1,500 |
| - grape pomace | 0.16 | 30% | 111 | 32.9 | 1,600 |
| - citrus pulps | 0.30 | 75% | 311 | 42.9 | 9,700 |
| - tomato peels | 0.003 | 70% | 318 | 37.5 | 98 |
| **Agrowastes - animals** | **0.10** | **0.04** | | | **1,955** |
| - abbattoir waste products | 0.02 | 50% | 517 | 138.8 | 1,155 |
| -whey and dairy wastes | 0.08 | 40% | 372 | 23.4 | 800 |
| **Residual crops (*)** | **0.80** | **0.16** | | | **19,150** |
| - total (straw, leaves, cobs) | 0.80 | 20% | 190 | 120 | 19,150 |
| **TOTAL RESIDUAL BIOMASS** | **6.65** | **1.76** | | | **86,140** |

(Source: CIB, CRPA, University of Catania)

### *b. Ground-cover crops*

In Sicily, ground-cover crops for anaerobic digestion play an important role and could have positive knock-on benefits from the creation of a new rural grid for the energy feedstock production (Lewis, 1987). The issue is about land which is ‘uncultivated’ for some months of the year or all year for economic or logistic reasons or due to reductions in the livestock industry.

It’s well known that the intensification of cropping system could have some effects on soil water conservation. Biogasdoneright management involve the use of the digestate on the soils. It improves soil water storage and reduce the stress that could be associated to the sequential crops system (Selvaggi et al., 2018).

Regarding the double crops, the second harvest are subject to periods of greater probability of rains in late summer or in early autumn; this does not happen for the monocrops.

Furthermore, legumes following cereals (i.e., Italian sainfoin) in rotation might fix more nitrogen in the soil and have several benefits such as reducing soil erosion, improving organic soil matter and thereby water resources. Green meadows could have a role in climate change: $CO_2$ will be fixed through chlorophyl photosynthesis.

The principal ground-cover crops cultivated in Sicily for energy use, without introducing new species, are essentially 2:

- Hedysarium coronarium L. (Italian sainfoin) in rotation with durum wheat on farms without irrigation systems;

- Sorghum spp. for second harvest on farms with drip irrigation systems.

Sicilian agriculture consists of more than 200,000 farms (source: ISTAT 2011) meaning 13.6% of the Italian farm total covering more than 1.5M hectares of Total Agriculture Area (TAA) or 1.4M hectares of UAA: 9.1% of Italian TAA plus 10.8% of UAA. Sicilian UAA in 2010 represented a total of 1,387,521 hectares subdivided into 49.1% cropland, 23.1% grassland and 27.7% forestry (Table 3, source: ISTAT 2010). In the local agricultural economy, a big part is played by citrus and olive orchards and vineyards (Valenti et al., 2017b) which are commercialised not only fresh but are also processed by local industry that export juices, oil and wine.

**Table 3 – Use of farmland in Sicily, 2010**

| Description | hectares | |
|---|---|---|
| **TAA** | **1,549,417** | |
| **UAA** | **1,387,522** | *100%* |
| Praires and pastures | 320,354 | *23.1%* |
| Orchards | 384,300 | *27.7%* |
| Others | 2,173 | *0.2%* |
| Cropland | 680,695 | *49.1%* |
| - Coarse grain cereals | 317,044 | |
| - Pulses | 26,173 | |
| - Potatoes | 1,097 | |
| - Feed roots and brassicas | 2,910 | |
| - Industial crops | 549 | |
| - Ortive | 30,565 | |
| - Feed crops in rotation | 199,605 | |
| - Set aside (1) | 98,617 | |
| - Others | 4,135 | |

(Source ISTAT, 2010)
(1) Here are included all the farmland in rotation, tilled or not, that in the year are:
- kept bare without any cultivation;
- covered with native vegetation that can be used ad feed or green mulching.

Italian Sainfoin can be grown on about 72,000 hectares of land earmarked by ISTAT as ‘set aside lands’ whereas Sorghum spp. could be cultivated on 8% of land set aside for cultivating pulses, course grain cereals and feed crop rotations on a total surface area of about 62,000 hectares.

Furthermore, perennials such as Opuntia spp. can be cultivated on land earmarked as ‘prairies and pastures’ in Sicily and other Mediterranean areas which are often seen as critical from an environmental standpoint, since they are prone to erosion, desertification and fires.

Recent studies at the University of Catania show that growing perennial plants also benefits the soil, reduces the risks associated with soil erosion and helps increase organic soil matter. Some of these perennial crops might also be used profitably in anaerobic digestion, particularly Opuntia spp, also known as prickly pear cactus (Santos et al., 2016). This plant has been cultivated for centuries in Sicily, mainly for its edible fruit. Prickly pear cactus and other CAM plants can also be used as animal forage, have good yields and suitable water content for anaerobic digestion. Thus, prickly pear cactus is a multiple use plant being drought-tolerant and highly suitable for arid regions and poor soils. Drought tolerance also permits the utilization of the southern slopes of hills in the Sicilian hinterland, where erosion and desertification are widespread. The project is to cultivate a green lawn of Opuntia spp, different from the traditional planting pattern. In Mediterranean area, the total land cover and the effect of plant roots are solutions for erosion control. The development of Opuntia plants cover will provide shelter from rains: rainfall energy is the prime cause of erosion from tilled or bare land, occurring when the soil lacks protective vegetative cover (Zuazo and Pleguezuelo, 2008).

Growing Opuntia spp. or another endemic perennial crop on about 1% (about 3,000ha) of the area earmarked as ‘praires and pastures’ in Sicily would be a reasonable estimate.

Overall, ground-cover crop cultivation involves around 138,000 hectares accounting for 10% of the total Sicilian UAA.

Considering the specific biomethane yield of Italian sainfoin calculated by the CRPA-Lab equals about 2,700 Nm3/ha, Sorghum equals about 2,500 Nm3/ha and Opuntia equals about 2,900 Nm3/ha, the total biomethane production by ground-cover and perennial crops is about 350M Nm3/year, in line with the 2030 target in Table 1.

Therefore, together with residual biomass, these crops are the true unexploited potential of Sicilian agriculture for bio-methane production: those 138,000ha of crops that, without the demand created by AD, would not be produced. In our judgement, together with residual biomasses, these crops represent the biomass that should be used to produce advanced biofuel, since they have no impact on the crops needed for food and the feed market. Biogasdoneright management at a farm triggers higher productivity coupled to higher sustainability of farming and livestock practices, increased soil fertility and therefore ultimately strengthens the food and feed output of farms and the food security of the country as a whole.

### *c. Biogas from Municipal Organic Waste*

For reference a brief note on the potential of biogas from municipal organic waste is added taken from official data provided by the Institute for Environmental Protection and Research. According to the 2015 Waste Report (ISPRA, 2015) on Sicily in 2014, the production of municipal waste amounted to 2.3M tons.

In 2014, at the national level, the percentage of collected municipal organic waste amounted to 45.2% of national production with 13.4M tons collected, an increase of nearly 3% compared to 2013 (42.3%). In Sicily, the room for improvement is considerable, since collection accounts for only 12.5%.

Nationwide, the municipal organic waste (kitchen food waste and maintenance of green waste, or the biowaste) of municipal solid waste destined for recovery is a very significant share of the total amount of municipal waste collected separately: 5.7M tons of 'biowaste' in 2014 accounted for 43% of municipal waste collected separately and sent for recovery.

In the Italian waste management system, municipal organic waste is usually processed by the composting industry, a well-structured sector that couples aerobic and anaerobic treatment and which produces soil amendments.

Given the current situation, there is a greater margin for development than in other regions in separating Sicily's organic waste which would lead to the great advantages of integrating aerobic with anaerobic treatment, and therefore in the short and medium to long term would release the potential of biomethane generated from MSW in Sicily.

## 2.2 Monocrops

In our assumptions, we forecast that in Sicily an area of about 28,000ha has to be gradually set aside exclusively for digester crops, corresponding to about 2.0% of the Sicilian UAA, a realistic surface area and certainly less than the technical and economic potential. In the past, a substantially larger agricultural area in Sicily was used to produce feed for the livestock industry; yet, today with the decline in the livestock industry, this land has become marginal and often abandoned, especially land with a high clay fraction and therefore unsuitable for fruit trees. In such soils, i.e. a sorghum silage monocrop can yield 4,440 Nm3 of biomethane/ha, with a production of 40 t/ha and a productivity of 111 Nm3 CH4/t of biomass (source: database CRPA). By these calculations, 28,000ha could produce approximately 124.3 million Nm3 of natural gas (4,440 Nm3 x 28,000 ha) or about 22% of the 2030 Sicilian objective.

## 3. DISCUSSION

This paper focuses on Biogasdoneright™ applications in Sicily for the more efficient use of agricultural land and a reduction in current Sicilian agricultural GHG emissions. In particular, the focus is on the potential of biomethane production through a process of gradual upgrading.

Sicily has so far participated only marginally in the development of Italian biogas, with only 5 biogas plants as opposed to more than 1,400 biogas plants operating throughout the rest of Italy.

The proposed plan aims to produce about 562M Nm3/year of biomethane in Sicily using only 50 hectares of monocrop, with a Land Efficiency of about 20,000 Nm3 of biomethane per hectare. It would be used in transport and future industrial applications by injecting bio-methane into the natural gas grid. This biomethane production would lead to a reduction in only 28,000 hectares of land to forage crops and food (2%

of the UAA of the Sicilian region), yet it would cover almost 80% of the land required for advanced biofuels by using:

- Waste by-products which would produce about 85 million Nm3 of biomethane (15% of the target) and furthermore would significantly mitigate the amount of greenhouse gas emissions along the value chain;

- Ground-cover crops would produce about 350 million Nm3 of biomethane (65% of the target) from crops that otherwise would not have been cultivated for lack of local demand involving 140,000ha (10% of Sicilian UAA) of mainly set-aside land or bare land rotated between two food crops.

Thanks to clear European and Italian legislation on the kind of ground-cover crops and by-products/agro waste suitable for advanced biofuel production, Sicily has all the right framework conditions to participate in the program of developing the use of CNG/LNG for transport. In this sector, Italy is already one of the world leaders in NGVs and determined to consolidate its leadership in the coming years also by expanding the use of biomethane to about 8 times the current consumption of NG as an alternative fuel.

**Table 4** – GAS for transport: Italian state of the art and "aspirational" future to 2030

| | Vehicles | CNG fueling stations | Gas consumption |
|---|---|---|---|
| | [n] (.000) | [n] | Bm$^{3}$* |
| **2008** | 520 | 700 | 0,6 |
| **2014** | 885 | 1000 | 1 |
| **2030 **** | 4-5.000 | 2500 | 6-8 |

(Source: Società Nazionale Metanodotti (SNAM), 2016)
* Billions of m$^3$
** Aspirational

It is worth noting that with the recent approval of the Network Code of SNAM, network-injected biomethane corresponds to all the required specifications of natural gas and therefore there are no technical limitations to its use nor any mixing limits.

Biomethane could therefore contribute 2% to the Italian advanced biofuels [6] target considering the forecast for the growth in CNG / LNG consumption of 8Bn Nm3 by 2030.

## 4. CONCLUSION

In conclusion it should be noted that Sicily can contribute, as can the rest of Italy, to the 2030 objective, by resorting to a minimum quantity (2% of UAA) of dedicated crops, and by

[6] Italy, even before the adoption of the RED 2015/1513, adopted a law that push for a 2% advanced biofuel in consumption by 2022 (decree passed in 2014)

making use of residual biomass with ground-cover crops in annual rotation and not with food and forage crops as described in Annex IX paragraph A, subparagraph p of the EU 2015/1513 Directive. Those crops would not be produced in the absence of digesters, because there is no market for them as Food or Feed.

The dissemination of Biogas refineries in the territories of Southern Italy is therefore important as it would mean a higher penetration of intermittent Renewable Energy sources (PV and wind above all) due to the electricity from biogas being programmable and therefore suited to help stabilise the power grid. Moreover, the electricity from biogas can provide a larger share of clean electricity to power rising electrical mobility with clean energy (Röder, 2016). This would be facilitated with a biogas refinery, decentralized at the farm site, where digestate is used as fertilizer, in substitution or in addition to chemical fertilizers, connected to two different grids (Power and Electricity), and able to produce electricity and thermal energy, biofuels, food and feed in a flexible and programmable way to suit market conditions.

Biogas production by Biogasdoneright principles involves producing an advanced biofuel, and making the best use of Sicilian agricultural soils. This can be achieved while avoiding any possible competition with food and feed crops, and moreover contributing countless agronomic, economic, environmental and social benefits to Sicilian agriculture.

The positive effects on the environment in particular from increased photosynthetic activity due to longer soil coverage by crops, more efficient use of waste and by-products and proper digestate or biofertilizer utilization can generate positive effects on the agriculture and economic sector as well. Moreover, the production of CNG and LNG in the transportation sector lets agrifood products reach the markets with a lower carbon footprint with a knock-on effect for consumer choice (Ǎhman, 2010).

Additionally, the AD infrastructure is fundamental in mitigating agricultural emissions, and agrifood waste and by-product treatment also mitigates and almost totally eliminates the contamination of surface and ground-water sources thanks to the recovery of nitrogen and its proper use in agriculture.

Last but not least, it should be noted that comparing current agriculture practices, thanks to improved rotations and farmers' innovations with ground-cover crops for AD, agricultural biodiversity is greatly increased with all the knock-on benefits associated with it for the landscape and Nature.

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# Estimating willingness to pay for digestate: evidence from an economic experiment from Sicilian farmers

Selvaggi, R., Chinnici, G., & Pappalardo, G.

## Abstract

*In this study, we estimated the willingness to pay of Sicilian farmers to buy the digestate which is a by-product of anaerobic digestion process of biomass. We argued that variation of the degree of information about digestate alters farmers' willingness to pay for it. In particular, through a second price experimental auction, we evaluated whether waiting for additional future information on digestate would influence farmers' willingness to pay. Our results show the existence of a positive farmers' willingness to pay for digestate and a delay effect value arising from the option value of being able to wait and learn more about the value of the digestate. This implies the necessity for policy makers to provide farmers with an appropriate level of information about the digestate's attributes.*

**KEYWORDS***:* Biomass; Digestate; Willingness to pay (WTP); Experimental auction.

# 1. INTRODUCTION

Digestate is part of the biogas chain, an optimum example of circular economy which is a closed-cycle system in which all the products are resources and none are waste (Ammenberg and Roozbeh, 2017; Chinnici et al, 2015). Fundamental to closing the cycle, is the correct agronomic use of digestate which plays a key role in improving the environmental compatibility of anaerobic digestion with the surrounding environment both in terms of reducing costs and farmers' dependence on industrial fertilisers (Cerruto et al, 2016; Selvaggi et al., 2017; Valenti et al., 2017a; Zecca and Rastorgueva, 2017). The production of digestate come into the „biofuels done right" (Dale et al, 2010) and „biogas done right" (Dale et al., 2016) principles which refer to integrating anaerobic digestion within the farm without reducing food or fertiliser production.

Currently, the use of digestate is widespread only in those areas where anaerobic digesters are present such as the Northern regions of Italy. In other areas, such as in the Mediterranean regions, despite the high potential of available biomass, the number of anaerobic digestion plants is very low and the use of the digestate as soil improver is still very limited (Manetto et al., 2016; Chinnici et al., 2018). Nevertheless, since the profitability of digesters is traditionally dependent on public subsidies (Appel et al., 2016), the opening of new markets for the marketing of digestate could create new income opportunities for plant managers (Fabbri et al., 2010; Dahlin et al., 2017; Safonte et al., 2018).

In Sicily (Italy), where the survey presented in this paper has been conducted, anaerobic digestion can make use of at least three macro-categories of biomass: 1) waste and agricultural and agro-industrial by-products (e.g. olive residues, citrus pulp, whey) which are often treated as wastes; 2) silage from traditional Mediterranean crops in rotation or the second harvest of the main crops chosen according to irrigation availability; 3) silage or plant cuttings from typically Mediterranean bushy crops (e.g. Prickly pear, Opuntia spp) grown on marginal land. All of the above biomasses are suitable for the production of digestate within the principle of „biogas done right" but the number of digestate plants currently operating in Sicily is very low (Valenti et al., 2017b; Selvaggi et al., 2018).

An important condition for enlarging the digestate market is to provide farmers with the necessary information on the physical and chemical properties of it and on the benefits that the digestate brings to agricultural land if it is used as organic soil improver (Dahlin et al., 2015). The lack of such information could create considerable uncertainty among farmers on its real value with potential negative repercussions on willingness to pay (WTP) to buy the digestate.

With this background, the objective of this study is to assess whether the level of knowledge of farmers about the attributes of the digestate can influence the willingness to pay to buy it. To this end, a survey was conducted in Sicily (Italy) on a sample of 223 farmers correlating the willingness to pay to buy digestate with a set of attributes that usually distinguish the category of organic soil conditioners. An experimental design was structured in which participants were given a different waiting time to formulate their willingness to pay and different levels of information on digestate attributes delayed over time. In this way, it was possible to determine whether the availability of information on certain attributes of the digestate influences the farmers' willingness to pay to purchase it.

## 2. METHOD SECTION

From April to June 2017, 223 Sicilian farmers (owners or managers) were interviewed all of whom are involved in decision making regarding farm machinery purchase. Farmers participated in a non-hypothetical experimental auction (Lusk and Shogren, 2007; Wongprawmas et al, 2016; Pappalardo et al, 2016a; Pappalardo and Lusk, 2016b;

Pappalardo et al, 2017) and in particular in a “second price” experimental auction (Vickrey auction) (Vickrey, 1961) to elicit WTP for the digestate.

When the farmers were recuited, they were asked about some screening questions: 1) Were they owners or managers of the farm? 2) Were they responsible for acquiring farm machinery? 3) Did they use soil conditioners on the farm or would they be interested in doing so? If all the answers were affirmative, farmers were invited to take part in the survey by meeting up one day at a predetermined time to be interviewed using the experimental auction method.

The farmers in the experimental auction were each assigned a personal ID number and given a bag of bidding tickets so as to be able to bid anonymously during the auction experiment. Once the farmers were all seated, the coordinator explained that the experimental auction consisted of various rounds and that each participant would make various bids to acquire digestate. With all the rounds over, one round would randomly be selected to reveal the auction winner and the second highest bid which would represent the market price. The number of rounds depended on the experiment treatment the farmer had been allocated to but in never treatment, after each round, data on the highest bid and the second highest bid which determined the sale price were provided.

Prior to the experimental auction with the digestate, five test rounds were carried out with an anonymous test product (a 500 gram packet of spaghetti). This auction was only to familiarise the bidders on the protocol.

In the real auction, the bidding was for a ton of digestate.

The auction winner received a coupon for a ton of solid digestate at market price from a known producer. The farmers' bids did not include transport costs from the producer to the auction winner's farm.The interviews took place in Sicily in various rural areas such as to involve farms with varying crops. To incentivise their participation in the survey, each participant was given €10 of food products.

## 2.1 Experimental design

The experiment was designed with four treatments subdividing the farmer sample into four subgroups to which bidders were randomly assigned.

In the first treatment "T1- control group" (56 members), the experimental auction had only one round and its members were only provided with basic information on digestate and shown a sample of digestate. No information on the attributes of digestate was provided to the participants.

In the second treatment "T2" (55 members), the experimental auction had 5 rounds and bidders were given the same basic information on digestate as in the previous group and shown the same sample of digestate. No information on the attributes of digestate was provided to the participants.

In the third treatment "T3" (56 members), the experimental auction had 10 rounds and the bidders were given the same basic information as in the 2 previous groups as well as the same sample of digestate.

In the final 4th treatment "T4" (56 members), the experimental auction had 10 rounds, but bidders were told that after the first five rounds they would receive additional information on digestate regarding the attributes of it. The bidders made their first five bids on the basic information received in the 3 previous treatments. Subsequently, bidders made 5 more bids having received the additional digestate information. These information were related to the following 8 attributes selected by main literature on the topic (e.g. Dahlin et al., 2017; Hou et al., 2017):

1) "Organic origin",
2) "Soil fertility",
3) "Environmental sustainability",
4) "Local production",
5) "Safety",
6) "Price",

7) "Natural product",
8) "Microbial activity".

For the above digestate's attributes we also assessed the relative importance assigned by farmers by using the Best-Worst scaling (BW) approach, which was originally introduced by Finn and Louviere (1992) and was further developed by Marley and Louviere (2005). Respondents were shown a set of items and were asked to indicate which was the best and which was the worst (or, in this case, which was most and least important). Respondents made several repeated choices where the set of items varies across questions. In our survey, the items used in Best-Worst questions were the eight digestate's attributes as previously listed.

To determine which combination of attributes to present to respondents, we utilized a Balanced Incomplete Block Design (BIBD). The 8 items (8 attributes) were assigned in groups of five to 8 different BW questions (i.e., there were 8 BW questions, each containing five of the attributes). To analyze the data obtained from the BW questions, we counted the number of times that a respondent chose an attribute as the most important and subtracted the number of times that the same respondent chose the same attribute as least important across the eight questions. Because each attribute appeared five times, the highest possible score is +5 and the lowest is -5.

## 2.2 Results

### *2.2.1 Demographic characteristics*

Table 1 shows the main socio-demographic characteristics of the farmer samples interviewed in the four experiment treatments. For the four interviewed groups, men predominate and the prevalent mean ages are between 18-39 and 40-49. The prevalent level of education is Middle School Diploma and the prevalent income of farms run by the interviewees was more than € 50,000 per year. The main farm crops were seed crops and field horticulture.

*Table 1 – Socio-demographic characteristics (*)*

| | (T1) (56 units) | (T1) (55 units) | (T3) (56 units) | (T4) (56 units) | Total sample (223 units) |
|---|---|---|---|---|---|
| Gender | | | | | |
| *male* | 92.9% | 94.5% | 94.6% | 96.4% | 94.6% |
| *female* | 7.1% | 5.5% | 5.4% | 3.6% | 5.4% |
| Age | | | | | |
| 18-39 | 32.1% | 38.2% | 37.5% | 25.0% | 33.2% |
| 40-49 | 32.1% | 29.1% | 39.3% | 44.6% | 36.3% |
| 50-65 | 30.4% | 21.8% | 16.1% | 25.0% | 23.3% |
| > 65 | 5.4% | 10.9% | 7.1% | 5.4% | 7.2% |
| Qualification | | | | | |
| *Elementary school* | 3.6% | 9.1% | 7.1% | 3.6% | 5.8% |
| *Middle school* | 28.6% | 29.1% | 39.3% | 46.4% | 35.9% |
| *High school Diploma* | 35.7% | 38.2% | 39.3% | 30.4% | 35.9% |
| *Degree* | 30.4% | 21.8% | 14.3% | 17.9% | 21.1% |
| *Other* | 1.8% | 1.8% | 0.0% | 1.8% | 1.3% |
| Farm income (€/year) | | | | | |
| *Less than 10,000* | 14.3% | 12.7% | 16.1% | 8.9% | 13.0% |
| *10,000 – 19,999* | 28.6% | 27.3% | 32.1% | 23.2% | 27.8% |
| *20,000 – 39,999* | 25.0% | 25.5% | 30.4% | 19.6% | 25.1% |
| *40,000 – 49,999* | 5.4% | 1.8% | 8.9% | 1.8% | 4.5% |
| *50,000 +* | 26.8% | 32.7% | 12.5% | 46.4% | 29.6% |
| Crops | | | | | |
| *Seed* | 53.6% | 43.6% | 69.6% | 42.9% | 52.5% |
| *Fruit* | 7.1% | 9.1% | 10.7% | 10.7% | 9.4% |
| *Citrus* | 8.9% | 7.3% | 5.4% | 8.9% | 7.6% |
| *Livestock* | 10.7% | 12.7% | 1.8% | 1.8% | 6.7% |
| *Field Horticulture* | 17.9% | 23.6% | 1.8% | 35.7% | 19.7% |
| *Greenhouse Horticulture* | 0.0% | 1.8% | 5.4% | 0.0% | 1.8% |
| *Other* | 1.8% | 1.8% | 5.4% | 0.0% | 2.2% |

(*) Source: our elaborations.

### *2.2.2 Statistics of Best-Worst scores for digestate's attributes*

Results of the BW analysis applied to the attributes of digestate are shown in Table 2. "Soil fertility" is on average the most important attribute across the four treatments while "environmental sustainability" and "natural product" were the next most important attributes on average. The other attributes with positive scores were "microbial activity" and "organic origin". On the contrary, the least important attributes for farmers are "local production", "safety" and, quite surprisingly, "price".

*Table 2 - Statistics of Best-Worst scores for soil conditioners' attributes (*)*

| | T1 | T2 | T3 | T4 |
|---|---|---|---|---|
| Organic origin | 0.46 | 0.67 | 0.11 | -0.16 |
| Soil fertility | 1.66 | 1.36 | 1.71 | 1.61 |
| Environmental sustainability | 0.79 | 0.65 | 0.27 | 0.34 |
| Local production | -1.43 | -0.82 | -1.16 | -0.57 |
| Safety | -0.57 | -1.00 | -0.88 | -0.63 |
| Price | -0.66 | -0.60 | -0.07 | -1.09 |
| Natural product | 0.48 | 0.55 | 0.27 | 0.77 |
| Microbial activity | 0.21 | 0.33 | 0.34 | 0.61 |

(*) Source: our elaborations.

### 2.2.3 Willingness to pay for digestate

Table 3 shows the average values for willingness to pay (WTP) in the 4 treatments. The average bid was highest for T1 group at €15.82 whereas the lowest average bid was for T3 at €5.77. This result could mean that although the participants do not know exactly what will be learned from the additional rounds of the experimental auction, the very fact that there are more opportunities to learn through more bids would seem to lower the WTP in the T3 treatment compared to T1 and T2. Moreover, in the T4 treatment, the average bid in the first 5 rounds (T4a) was much lower than in the final 5 rounds (T4b) having received the additional information on digestate.

*Table 3 – Willingness to pay for digestate (euro/ton) per treatment (*)*

| **Treatment** | **mean** | **St-Dev** |
|---|---|---|
| | **[€/ton]** | |
| (T1) | 15.82 | 16.89 |
| (T2) | 13.72 | 12.76 |
| (T3) | 5.77 | 8.63 |
| (T4) | 11.09 | 9.31 |
| *T4a* | *6.27* | *6.58* |
| *T4b* | *15.92* | *15.10* |

(*) Source: our elaborations.

## CONCLUSION

In this study it was observed that the farmers' willingness to pay for digestate increases when the farmer is provided with more information about it.

By means of the various treatments applied, we were able to highlight a dual characteristic. Above all, the mean willingness to pay decreased as the bid number rose, that is the delay bidders were subjected to during the experimental auction. In other words, the mean WTP in treatment T1 was higher than the mean WTP of treatment T2 and so on for treatment T3.

Furthermore, in the T4 treatment, participants were only given additional detailed information about the digestate after the first 5 bidding rounds. This information was provided prior to acquisition (revealing the winning bid and 2nd highest bid) and participants were told they would receive such information only after the first 5 bidding rounds. Our study showed that the highest willingness to pay for digestate was by treatment T4b who received information beyond the basic which all the other groups had been provided with.

This result reflects the mechanism that might happen in the real market where actual purchase may or may not occur after the consumer has been sufficiently informed about a particular good.

In conclusion, this study has estimated the willingness of a sample of Sicilian farmers to pay for digestate as a farm soil conditioner. The results appear to be interesting even though we are not absolutely sure that they are due to the experiment's design or that we have actually elicited the real farmers' WTP for digestate. In fact, our study proposes a methodological approach which could be further tested for digestate in other socio-economic contexts.

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# Factors affecting purchasing process of digestate: evidence from an economic experiment on Sicilian farmers' willingness to pay

Pappalardo, G., Selvaggi, R., Bracco, S., Chinnici, G., & Pecorino, B.

## Abstract

*In this study we evaluate from the perspective of the theory of commitment costs, if the level of farmer understanding about digestate attributes could influence the willingness to pay (WTP) for it. For this purpose, we carried out a research on a sample of 223 Sicilian farmers to correlate their WTP for digestate with a set of 8 attributes which usually characterise organic soil conditioners. An experimental design was set up so that participants were given different waiting times to decide on their WTP and different levels of information on the attributes of organic soil conditioners. The results highlight a positive WTP but farmers are strongly influenced by how much information is available on digestate. Without it, farmers' WTP decreases drastically probably due to phenomena correlated to what economic theory calls commitment costs.*

**Keywords**

*Willingness to pay; Digestate; Experimental auction; Commitment costs;*

## 1. Introduction

Digestate is an organic soil conditioner obtained after anaerobic digestion, a biochemical energy conversion process without oxygen. Anaerobic fermentation consists of using micro-organisms to break down the organic complexes (fats, proteins, carbohydrates) of plant and animal by-products. Digestate is an optimum organic soil conditioner, rich in nitrogen, phosphorous and potassium. It is more homogeneous compared to the biomass introduced in the anaerobic digesters on which its chemical composition depends (Tambone et al., 2013; Nkoa, 2014).

International research (Risberg et al., 2017; Bezzi and Ragazzoni, 2014) has shown positive effects from digestate on soil quality. Furthermore, positive effects on soil fertility have been highlighted due to its promptly available nutritional contribution to crops. Digestate also has a long-term effect on soil fertility due to the interaction of its organic fraction with the biochemical dynamics of the soil (Saveyn and Eder, 2014). After anaerobic digestion, digestate frequently undergoes separation into a solid fraction used as a manure substitute and a clarified fraction containing nitrogen as ammonia, a fast-acting nutrient for crops (Adubaker et al., 2012).

Currently, digestate is mainly used in those geographic areas where anaerobic digesters are widespread. In other areas like the Mediterranean basin, despite the high biomass potential available, the number of anaerobic digesters is very low and the use of digestate as soil conditioner is even more limited (Appel et al., 2016; Manetto et al., 2016; Chinnici et al., 2018). However, increasing the number of anaerobic digestion plants does not seem sufficient to promote the use of digestate as soil conditioner since its chemical-physical properties are yet little known among farmers (Fabbri et al., 2010; Dahlin et al., 2017).

An important condition for widening the digestate market is informing potential users about its chemical/physical properties and its benefits for soil improvement (Dahlin et al., 2015). A lack of data on digestate characteristics could create significant uncertainty among farmers on those benefits. Such uncertainty could also have negative repercussions on the use of digestate as a conditioner and consequently on the willingness to pay (WTP) for digestate notwithstanding the market potential. So, where digestate is little or completely unknown, informing farmers on its benefits might influence their WTP.

In conditions of uncertainty about the value of an asset, the estimate of the WTP as well as the identification of factors that influence the WTP could be affected by the possibility for potential consumers to delay the purchase to acquire future information on the same asset. An interesting approach that economic theory suggests for estimating the WTP of a good little known among potential users is the theory of Commitment Costs. (Zhao and Kling 2000, 2001 and 2004).

In such conditions, economic theory suggests that WTP for a good does not solely depend on its intrinsic characteristics, but also on other factors such as a good's uncertainty level, the time available to make a purchase decision or the level of withdrawal from a purchase. Zhao and Kling (2000, 2001 and 2004) have deduced that there is a commitment cost associated with a decision to purchase today which forgoes any future option to acquire additional information about a good. Consequently, commitment costs may have significant effects in estimating WTP and its consequent implications.

Despite numerous studies having highlighted the existence of commitment costs (e.g. Johannesson et al., 1999; Lusk, 2003; Corrigan, 2005; Corrigan et al., 2008; Kling et al., 2013; Bazzani et al., 2017), and their influence on the WTP, a little explored idea regards identifying the intrinsic characteristics or attributes of an asset which may influence WTP when there are commitment costs or which may contribute to arising them. Knowing little about an assets attributes may give rise to consumer uncertainty on the real value of an asset and consequent delay while further information is sought prior to purchase. In the case of digestate, knowing little about its chemical/physical properties could create farmer uncertainty about its use with consequent repercussions for the WTP (Jones et al., 2010) because of commitment costs.

So, on these premises, the aim of this study is to evaluate from the perspective of the theory of commitment costs, if the level of farmer understanding about digestate attributes could influence the WTP. Thus, research was carried out in Sicily (Italy) on a sample of 223 Sicilian farmers to correlate their WTP for digestate with a set of 8 attributes which usually characterise organic soil conditioners. An experimental design was set up so that participants were given different waiting times to decide on their WTP and different levels of information on the attributes of organic soil conditioners. In this way, it was possible to determine which digestate attributes influenced their WTP by varying waiting times and information levels.

Below, there is some brief data on the potential for biogas and digestate in Sicily where our research was conducted.

## 2. Background information

Digestate is part of the biogas chain, an optimum example of circular economy which is a closed-cycle system in which all the products are resources and none are waste (Ammenberg and Roozbeh, 2017). Fundamental to closing the cycle, is the correct agronomic use of digestate which plays a key role in improving the environmental compatibility of anaerobic digestion with the surrounding environment both in terms of reducing costs and farmers' dependence on industrial fertilisers (Chinnici et al., 2015; Selvaggi et al., 2017; Valenti et al., 2017a). Inspired by "biofuels done right" (Dale et al, 2010) which refers to integrating anaerobic digestion within the farm without reducing food or fertiliser production, 'biogas done right' term has been coined (Dale et al., 2016).

Due to the 'biogas done right' principle, soils can be employed all year round, crop rotation can be diversified, industrial fertiliser consumption can be reduced by using digestate and renewable energy can be used for the needs of the farm (Cerruto et al., 2016; Valenti et al., 2017b). In Sicily, where this survey has been conducted, the principle of ‘biogas done right’ has considerable potential to be applied efficiently. In particular, in Sicily anaerobic digestion can make use of at least three macro-categories of biomass: 1) waste and agricultural and agro-industrial by-products (e.g. olive residues, citrus pulp, whey) which are often treated as wastes; 2) silage from traditional Mediterranean crops in rotation or the second harvest of the main crops chosen according to irrigation availability; 3) silage or plant cuttings from typically Mediterranean bushy crops (e.g. Prickly pear, Opuntia spp) grown on marginal land (Selvaggi et al., 2018a; Valenti et al., 2017c).

## 3. Procedure

From April to June 2017, 223 Sicilian farmers (owners or managers) were interviewed all of whom are involved in decision making regarding farm machinery purchase. They were recruited with the help of local agricultural unions and some Sicilian agricultural cooperatives. Farmers participated in a non-hypothetical experimental auction (Lusk and Shogren, 2007; Pappalardo et al., 2016a; Wongprawmas et al, 2016; Selvaggi et al., 2018b and 2018c). This type of experiment offers the advantage of providing an incentive for participants to truly reveal their preferences. A second price experimental auction mechanism was designed to elicit WTP for the digestate, and we couple these data with answers from a set of Best-Worst (BW) scaling questions that provide a score of the relative importance of various attributes of soil conditioners. By combining the two approaches, we are able to provide an estimate of attributes that can affect WTP for digestate.

In the first step of the study, we recruited farmers for the experimental auction and, at the same time, farmers were asked questions on knowledge of soil conditioners, digestate and demographic information. When the farmers were asked about their willingness to participate in the survey, the interviewers asked some screening questions: 1) Were they owners or managers of the farm? 2) Were they responsible for acquiring farm machinery? 3) Did they use soil conditioners on the farm or would they be interested in doing so? If all the answers were affirmative, those farmers were invited to take part in the survey by meeting up one day at a predetermined time to be interviewed using the experimental auction method. If even in this case they answered affirmatively, the farmers were invited to fill out a questionnaire asking for some socio-demographic data. In addition, the questionnaire contained questions, formulated with the BW method, on the relative importance of a set of soil conditioners' attributes.

In the second step of the study, the farmers WTP for digestate was evaluated by a 2nd price experimental auction (Vickrey auction) (Vickrey, 1961). Prior to the actual survey, a preliminary survey was carried out on a group of farmers with the double aim of testing the experimental auction protocol and working out the minimum sample size of farmers to interview. The interviews took place in Sicily in various rural areas such as to involve farms with varying crops. To incentivise their participation in the survey, each participant was given €10 of food products.

Because there was no specific literature data on the WTP for digestate in this location, a preliminary study was conducted to help determine sample size – i.e., the number of farmers to include in each experiment treatment. As will be described momentarily, we utilized four experiment treatments. A pre-test was carried out on a sample of 60 Sicilian farmers in four different sessions corresponding to our main treatment effects. Using these data, we found a standard deviation of 5.12 and using a critical effect size of 1.34 (based on differences in means across sessions), we calculated the need of sample size of 56 subjects per treatment to attain 80% power.

Below, more detail on BW scaling and the second price auction are provided.

### *3.1 Best-Worst scaling*

To identify the relative importance of different attributes in the soil conditioner purchasing decision, we used the BW scaling approach, which was originally introduced by Finn and Louviere (1992) and was further developed by Marley and Louviere (2005). Respondents were shown a set of items and were asked to indicate which was the best and which was the worst (or, in this case, which was most and least important). Respondents made several repeated choices where the set of items varies across questions.

In our survey, the items used in BW questions were 8 soil conditioners' attributes selected by main literature on the topic (e.g. Pappalardo and Lusk, 2016b; Dahlin et al., 2017; Hou et al., 2017). The 8 attributes and the definition of each are reported in Table 1.

*Table 1 – Organic soil conditioners' attributes*

| | |
|---|---|
| Organic origin | Organic soil conditioners are different to chemical fertilisers |
| Soil fertility | Organic soil conditioners have positive effects on soil fertility |
| Environmental sustainability | Organic soil conditioners production has no environmental impact |
| Local production | Organic soil conditioners are sourced locally |
| Safety | Organic soil conditioners are safe to use because they are not chemical products |
| Price | Organic soil conditioners costs |
| Natural product | Organic soil conditioners are natural products which contribute to producing healthier foods |
| Microbial activity | Organic soil conditioners improve microbial activity in the soil because they are rich in organic substances |

To determine which combination of attributes to present to respondents, we utilized a Balanced Incomplete Block Design (BIBD). The 8 items (8 attributes) were assigned in groups of five to 8 different BW questions (i.e., there were 8 BW questions, each containing five of the attributes). To analyze the data obtained from the BW questions, we counted the number of times that a respondent chose an attribute as the most important and subtracted the number of times that the same respondent chose the same attribute as least important across the eight questions. Because each attribute appeared five times, the highest possible score is +5 and the lowest is -5.

## *3.2 The experimental auction protocol*

The farmers in the experimental auction were each assigned a personal ID number and given a bag of bidding tickets so as to be able to bid anonymously during the auction experiment. Once the farmers were all seated, the coordinator explained that the experimental auction consisted of various rounds (depending on the treatment) and that each participant would make various bids to acquire digestate. With all the rounds over, one round would randomly be selected to reveal the auction winner and the second highest bid which would represent the market price (Vickrey auction) (Vickrey, 1961). The number of rounds depended on the experiment treatment the farmer had been allocated to but in never treatment, after each round, data on the highest bid and the second highest bid which determined the sale price were provided.

Prior to the experimental auction with the digestate, five test rounds were carried out with an anonymous test product (a 500 gram packet of spaghetti). This auction was only to familiarise the bidders on the protocol. In the real auction, the bidding was for a ton of digestate and consequently the auction winner really bought a ton of digestate paying the second highest price. The auction winner received a coupon for a ton of solid digestate at market price from a known producer. The farmers' bids did not include transport costs from the producer to the auction winner's farm.

### *3.3 Experiment treatments*

The survey was designed to evaluate whether waiting for additional future information on digestate would influence their WTP for it. So, the experiment was designed with four treatments subdividing the farmer sample into four subgroups to which bidders were randomly assigned.

In the first treatment 'Treatment 1' (T1, 56 members), the experimental auction had only one round and its members were only provided with basic information on digestate eg. where it was produced and how it worked on the soil. Members were also shown a sample of digestate in a container which they could touch and smell. No information on the attributes described above was provided to the participants.

In the second treatment 'Treatment 2' (T2, 55 members), the experimental auction had 5 rounds and bidders were given the same basic information on digestate as in the previous group and shown the same sample of digestate. No information on the attributes described above was provided to the participants.

In the third treatment 'Treatment 3' (T3, 56 members), the experimental auction had 10 rounds and the bidders were given the same basic information as in the 2 previous groups as well as the same sample of digestate.

In the final 4th treatment 'Treatment 4' (T4, 56 members), the experimental auction had 10 rounds, but bidders were told that after the first five rounds they would receive additional information on digestate regarding the attributes described above (Organic origin, Soil fertility, etc.). So, the bidders made their first five bids on the basic information received in the 3 previous treatments. Subsequently, bidders made 5 more bids having received the additional digestate information.

To avoid any issues of bias or affiliation (Corrigan et al, 2011), in none of the treatments was the winning bid revealed at the end of each round nor the second highest bid representing the market price. Table 2 shows the treatment characteristics.

*Table 2 - Treatment characteristics*

| | (T1) | (T2) | (T3) | (T4) |
|---|---|---|---|---|
| Auction protocol | Yes | Yes | Yes | Yes |
| Sample to touch and smell | Yes | Yes | Yes | Yes |
| Basic information | Yes | Yes | Yes | Yes |
| Detailed information | No | No | No | Yes |
| Winning bid feedback between rounds | No | No | No | No |

# 4. Results

## *4.1 Summary statistics*

Table 3 shows the main socio-demographic characteristics of the farmer samples interviewed in the 4 experiment treatments. The values of Fisher's exact test show that the samples in the 4 treatments show no differences in terms of gender, age, qualifications, farm income or crop type. In other words, the sample data set is compatible with the null hypothesis (H0) of equal means such that the original populations of the 4 experiment treatments have the same structure and that any observed differences with the sample data is due to chance.

In particular, for the 4 interviewed groups, men predominate and the prevalent mean ages are between 18-39 and 40-49. The prevalent educational rate is Middle School Diploma and the prevalent income of farms run by the interviewees was more than € 50,000 per year. The main farm crops were seed crops and field horticulture.

**Table 3 – Socio-demographic characteristics**

| | (T1) (56 units) | (T2) (55 units) | (T3) (56 units) | (T4) (56 units) | Total sample (223 units) |
|---|---|---|---|---|---|
| Gender | | | | | |
| *Male* | 92.9% | 94.5% | 94.6% | 96.4% | 94.6% |
| *Female* | 7.1% | 5.5% | 5.4% | 3.6% | 5.4% |
| *Fisher's exact test p-value: 0.613* | | | | | |
| Age | | | | | |
| 18-39 | 32.1% | 38.2% | 37.5% | 25.0% | 33.2% |
| 40-49 | 32.1% | 29.1% | 39.3% | 44.6% | 36.3% |
| 50-65 | 30.4% | 21.8% | 16.1% | 25.0% | 23.3% |
| > 65 | 5.4% | 10.9% | 7.1% | 5.4% | 7.2% |
| *Fisher's exact test p-value: 0.459* | | | | | |
| Educational rate | | | | | |
| *Elementary school* | 3.6% | 9.1% | 7.1% | 3.6% | 5.8% |
| *Middle school* | 28.6% | 29.1% | 39.3% | 46.4% | 35.9% |
| *High school Diploma* | 35.7% | 38.2% | 39.3% | 30.4% | 35.9% |
| *Degree* | 30.4% | 21.8% | 14.3% | 17.9% | 21.1% |
| *Other* | 1.8% | 1.8% | 0.0% | 1.8% | 1.3% |
| *Fisher's exact test p-value: 0.407* | | | | | |
| Farm income (€/year) | | | | | |
| *Less than 10,000* | 14.3% | 12.7% | 16.1% | 8.9% | 13.0% |
| *10,000 – 19,999* | 28.6% | 27.3% | 32.1% | 23.2% | 27.8% |
| *20,000 – 39,999* | 25.0% | 25.5% | 30.4% | 19.6% | 25.1% |
| *40,000 – 49,999* | 5.4% | 1.8% | 8.9% | 1.8% | 4.5% |
| *50,000 +* | 26.8% | 32.7% | 12.5% | 46.4% | 29.6% |

Table 4 shows the descriptive statistics for WTP in the 4 treatments. Comparing them, the statistics seem to favour the commitment costs theory and the delay effect to acquire future information. The average bid was highest for T1 (auction with only 1 round) at €15.82 whereas the lowest average bid was for T3 (auction with 10 rounds) at €5.77. This result might signify that despite not knowing exactly what might be explained in subsequent rounds, the fact that the farmers had the opportunity to learn through more bids, may have been sufficient to lower their WTP in treatment T3 compared to T1 and T2.

Moreover, T4, the average bid in the first 5 rounds (T4a) was much lower than in the final 5 rounds (T4b) having received the additional information on digestate.

*Table 4 – Willingness to pay for digestate (euro/ton) per treatment*

| Treatment | mean | median | minimum | maximum | St-Dev |
|---|---|---|---|---|---|
| | [€] | [€] | [€] | [€] | |
| T1 | 15.82 | 10.00 | 0.00 | 80.00 | 16.89 |
| T2 | 13.72 | 10.00 | 0.00 | 64.00 | 12.76 |
| T3 | 5.77 | 2.87 | 0.00 | 53.00 | 8.63 |
| T4 | 11.09 | 9.63 | 0.00 | 53.00 | 9.31 |
| *- T4a* | *6.27* | *2.95* | *0.00* | *28.00* | *6.58* |
| *- T4b* | *15.92* | *11.65* | *0.00* | *78.00* | *15.10* |

Results of the BW analysis applied to attributes of soil conditioners are shown in Table 5. Soil fertility is on average the most important attribute across the four treatments while environmental sustainability and natural product were the next most important attributes on average. The other attributes with positive scores were microbial activity and organic origin. On the contrary, the least important attributes for farmers are local production, safety and, quite surprisingly, price.

The exact values of the Fischer test show that the farmer samples in the 4 treatments show no points differences relative to the importance of the soil conditioners attributes with the exception of the 'organic origin' attribute which was evaluated negatively only by the farmers who participated in treatment T4. This highlights that in all treatments farmers had similar opinions on all the researched attributes. This homogeneity makes the results very comparable.

***Table 5 – Statistics of Best-Worst scores for soil conditioners' attributes***

| | T1 | T2 | T3 | [illegible] |
|---|---|---|---|---|
| Organic origin | 0.46 | 0.67 | 0.11 | -( |
| *Fisher's exact test p value=0.0801* | | | | |
| Soil fertility | 1.66 | 1.36 | 1.71 | 1 |
| *Fisher's exact test p value=0.7682* | | | | |
| Environmental sustainability | 0.79 | 0.65 | 0.27 | 0 |
| *Fisher's exact test p value= 0.4410* | | | | |
| Local production | -1.43 | -0.82 | -1.16 | -( |
| *Fisher's exact test p value= 0.1297* | | | | |
| Safety | -0.57 | -1.00 | -0.88 | -( |
| *Fisher's exact test p value= 0.5412* | | | | |
| Price | -0.66 | -0.60 | -0.07 | -1 |
| *Fisher's exact test p value=0.2757* | | | | |
| Natural product | 0.48 | 0.55 | 0.27 | 0 |
| *Fisher's exact test p value= 0.2067* | | | | |
| Microbial activity | 0.21 | 0.33 | 0.34 | 0 |
| *Fisher's exact test p value= 0.7319* | | | | |

### *4.2 Effect of soil conditioners' attributes on farmers WTP for digestate*

To estimate effects of soil conditioners' attributes on WTP for the digestate, four OLS regressions were estimated in which the WTP for the digestate was specified as a function of the BW scores. The dependent variables in the four OLS regressions were as follows: 1) WTP for the digestate with no delay and without information on digestate's attributes (T1), 2) WTP for the digestate with average delay and without information on digestate's attributes (T2), 3) WTP for the digestate with long delay and without information on digestate's attributes (T3), 4) WTP for the digestate with delayed information (T4). The independent variables in each regression are the scores related to the 8 attributes obtained through the BW scaling. The score of the attributes local production was omitted to avoid perfect collinearity (the sum of all BW values is always zero by construction).

The regressions showed which digestate attributes influence WTP by varying wait times and the possibility of acquiring further information. Table 6 shows that WTP for digestate is influenced by variables according to treatment. In treatment T1 where participants bid without a wait time nor with any information on the digestate, their WTP is significantly negative only for the 'security' attribute. In treatment T2, when participants could make 5 bids, WTP was influenced not only by ‘security’ but also by ‘natural product’ and ‘microbial activity’.

‘Environmental sustainability’ and ‘price’ were statistically significant in T3 where participants had long wait times to decide on their WTP (10 bids).

Finally, in T4, there were significant differences in the attributes which influence WTP. In the first 5 rounds (T4a), when participants had little detailed information on digestate, only ‘natural product’ was significant. By contrast, in the last 5 rounds (T4b), when participants had extra information on digestate, WTP was statistically influenced by all the attributes except by ‘natural product’.

***Table 6 – OLS regression of attributes affecting willingness to pay for digestate***

| ributes included in the models | T1 (1) | T2 (1) | T3 (1) | T4a (1) | T4b (1) |
|---|---|---|---|---|---|
| Const. | 11.774 *(0.0001)* *** | 9.4533 *(0.0001**** | 2.8795 *(0.0001**** | 3.9313 *(0.0002)**** | 13.417 (0.00001 |
| Organic origin | 0.4975 *(0.4212)* | 0.3214 *(0.7042)* | −0.1993 *(0.5890)* | −0.2564 *(0.6120)* | −2.6421 *(0.0084)* |
| Soil fertility | 0.9465 *(0.3159)* | −0.2672 *(0.6540)* | 0.3260 *(0.2872)* | −0.1544 *(0.7044)* | −2.2206 *(0.0001)* |
| ironmental sustainability | −0.4454 *(0.6843)* | −1.2449 *(0.1311)* | −0.4731 *(0.0629)* * | −0.57858 *(0.1294)* | −2.1899 *(0.0002)* |
| Safety | −1.8563 *(0.0859)* * | −2.8498 *(0.0016)* *** | −0.6556 *(0.2117)* | −0.4310 *(0.3795)* | −3.1472 *(0.0023)* |
| Price | −0.5677 *(0.4405)* | −0.2078 *(0.7163)* | −0.7885 *(0.0015)* *** | −0.5360 *(0.2100)* | −1.8548 *(0.0046)* |
| Natural product | 0.3112 *(0.7855)* | 3.1440 *(0.0028)* *** | 0.4772 *(0.3047)* | 1.1918 *(0.0289)* ** | −0.3263 *(0.726* |
| Microbial activity | 0.1671 *(0.8206)* | −0.7236 *(0.0894)* * | 0.2637 *(0.5272)* | −0.0036 *(0.9878)* | −1.0926 *(0.0170* |
| | $R^2 = 0.23$ | $R^2 = 0.75$ | $R^2 = 0.37$ | $R^2 = 0.30$ | $R^2 = 0.40$ |
| | *Adjusted* $R^2 = 0.12$ | *Adjusted* $R^2 = 0.72$ | *Adjusted* $R^2 = 0.27$ | *Adjusted* $R^2 = 0.20$ | *Adjusted* $R^2 =$ 0. |

*/alues in the brackets are p-values: *10%; **5%; ***1%*

## 5. Discussion

The results of our study show above all farmers' WTP for digestate as an organic soil conditioner for their farms. It confirms therefore that which has been highlighted by other studies – farmers' interest in digestate (Saveyn and Eder, 2014; Dahlin et al., 2017). This is a positive result which can help grow the environmental sustainability of anaerobic digestion on farms and increase income from biogas, traditionally dependent on state subsidies.

Furthermore, the studies' results confirm previous studies on the existence of commitment costs and their influence on the WTP for a certain asset (Lusk, 2003; Bazzani et al. 2017). In fact, a greater WTP for digestate was obtained when the participants were provided with detailed information on its attributes (treatment 4b).

This signifies that the information provided might have diminished the degree of participant uncertainty about digestate attributes, lowering commitment costs and consequently increasing the WTP. Moreover, confirming the results of previous studies (Corrigan, 2005; Corrigan et al., 2008; Kling et al., 2013), the WTP values obtained in this study change according to how much time participants had to come to a purchase decision. In particular, the WTP for digestate was lowest when participants had more time for their bids (T3), whereas it was highest when there was least decision time (T1).

Nevertheless, our studies' results go beyond those of the existing literature because in addition to highlighting commitment costs in the purchase process of digestate, the research tried to identify which digestate attributes are connected with the WTP by changing wait times and the level of available information. Identifying such attributes in different contexts might contribute to explaining why commitment costs arise in the digestate purchasing process.

Our study highlighted that the digestate attributes which influence the WTP probably due to commitment costs change according to the influx of extra information. With extra information on digestate, nearly all the attributes influenced, even if negatively, WTP. This has important implications for biogas and digestate since notwithstanding their undoubted interest, the farmers have a negative perception of the organic origin of digestate, the environmental sustainability of the production process, security, price and its effects on soil fertility.

These last results were not presented by T1, T2 or T3 which might lead to a misinterpretation regarding the factors influencing the purchase of digestate. To reinforce and make more widespread the use of digestate as a soil improver for farms, the causes should be investigated into the commitment costs factor to overcome farmers' perplexities about the properties of digestate. The lack of specific information on digestate characteristics significantly lowers their WTP due to commitment costs about the real characteristics and benefits for agricultural soil.

## 6. Conclusions

In this study, the WTP for digestate as an organic soil conditioner for their farms was evaluated for a sample of Sicilian farmers. The results highlight a positive WTP but farmers are strongly influenced by how much information is available on digestate. Without it, farmers' WTP decreases drastically probably due to phenomena correlated to what economic theory calls commitment costs.

Results of our study could have important implications for organic soil conditioner market and biogas sector. Understanding attributes affecting farmers' WTP for digestate can promote the market of digestate among farmers with positive effects on soil quality and soil fertility due to its promptly available nutritional contribution to crops. Moreover, our results could be important for biogas industry since digestate is currently mainly used in those geographic areas where anaerobic digesters are widespread. Understanding factors affecting purchasing process of digestate can booster the diffusion of digestate also in other areas like the Mediterranean basin where high quantities of biomasses are available but the use of digestate as soil conditioner is even limited since it is not well-known among farmers. Moreover, since the profitability of digesters is traditionally dependent on state subsidies, opening new markets to commercialise digestate could create new income opportunities for digester managers especially in those areas where the spread of anaerobic digesters is still low.

The authors are aware of certain limits in this study such as the location where the research was carried out or the number and appropriateness of attributes of the organic soil conditioners considered. Future research could further explore other digestate attributes which could influence WTP or verify the analysis model we adopted in other locations. However, our results highlight a positive perception of digestate by farmers which may have important implications for both the organic soil conditioner market as well as for the biogas industry within which digestate is a significant output.

**List of abbreviations**

WTP: willingness to pay

BW: Best-Worst

BIBD: Balanced Incomplete Block Design

**Availability of data and materials**

All data were acquired and elaborated by the authors. Data supporting the research are available by requesting to the authors.

## Competing interests

None of the authors have any competing interests in the manuscript.


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## Authors' contributions

The work is the result of the full cooperation of all authors. However, first author wrote the paragraphs 3 and 4.1; second author (corresponding author) wrote the paragraphs 2, 4.2 and 5; fourth author wrote the paragraph 1; third and fifth author wrote the paragraph 6 and they supervised the work.

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# Procedural Invariance as a Result of Commitment Costs: Evidence from an economic experiment on farmers' willingness to pay for digestate

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## Abstract

*We offer a conceptual explanation for some of the procedural invariance witnessed in experimental studies related to the concept of commitment costs, which is confirmed in a field experiment with Sicilian farmers valuing a renewable soil conditioner.*

**Keywords:** Commitment Costs, Willingness-to-pay, Experimental auction, .

**JEL Code**: D60; D83; C90

## 1. Introduction

Welfare analysis typically rests on calculating consumers' compensating or equivalent variation, but these measures often fail to capture the dynamic nature of consumers' valuations. In particular, researchers are often interested in measuring willingness-to-pay (WTP) for goods, such as environmental amenities or new food technologies, for which consumers have limited information and knowledge. In these instances where consumers have the opportunity to wait and gather additional information, Zhao and Kling (2000, 2001, 2004) have argued that commitment costs, or option values, can drive a wedge between a consumers' WTP for a good today and future compensating variation.

The empirical importance of commitment costs has been noted in a variety of contexts (e.g., Bazzani et al., 2017; Corrigan, 2005; Corrigan et al, 2008; Kling et al, 2013; Lusk, 2003), and yet it is a concept that has not widely utilized in valuation work. The purpose of this paper is to build on this empirical literature by testing for commitment costs in an experimental auction setting. In particular, we argue that seemingly innocuous variation in experimental procedures alters commitment costs in a way that can result in sizable changes in WTP. While there is a large literature documenting procedural invariance in experimental settings (e.g., Lusk et al, 2004; Lusk and Schroeder, 2006), there is comparatively less work explaining the causes. Our results suggest that procedural invariance need not arise from irrationality or behavioural-economic phenomena but rather are largely explained by the rational theory of commitment costs.

Zhao and Kling (2001, 2004) posited a commitment cost associated with the decision to purchase today. When a purchase is made, the consumer forgoes the option to acquire additional information about a good in the future. Commitment costs depend on the degree of uncertainty about the value for a good, the extent to which consumers expect to gather additional information, and the degree of reversibility of the purchase decision. When consumers are uncertain, expect to gather additional information in the future, or cannot reverse their decision, WTP will depend on more than the intrinsic characteristics of the good. Previous research has explored how variation in WTP is explained by exogenous changes in the degree of reversibility (Corrigan, 2005; Kling et al, 2013). Instead, we focus on the effect of exogenously varying expected future information – both in terms of the number of auction bidding rounds and in terms of knowledge of whether information on the good in question would later be provided. Our empirical analysis focuses on farmers' preferences for "digestate", an organic soil conditioner that is a by-product of anaerobic digestion used to produce biogas; determining these values are important in determining the social value of and returns to a renewable energy source.

## 2. Experiment design

From April to June 2017, 223 Sicilian farmers (owners or managers) who were involved in decision making regarding farm machinery purchase were interviewed. They were recruited with the help of local agricultural unions and some Sicilian agricultural cooperatives.

Each farmer's WTP for digestate was evaluated using a 2nd price experimental auction (Vickrey auction); the bidding was for a ton of digestate and consequently the auction winner really bought a ton of digestate paying the second highest price. Pre-tests were conducted prior to the primary auctions used in this paper to test for understanding of experiment instructions and to ascertain expected bid values so as to conduct power calculations for sample size determination. The pre-test was carried out on a sample of 60 Sicilian farmers in four different sessions corresponding to our main treatment effects. Using data of pre-test, we calculated the need of sample size of 56 subjects per treatment to attain 80% power.

## *2.1 Experiment treatments*

The experiment was designed to evaluate whether waiting for additional future information on digestate would influence WTP. The experiment consisted of the four treatment groups and farmers were randomly assigned to one and only one group (a between-subject design). Table 1 shows the treatments.

In the first treatment ‘Treatment 1’ (T1, 56 members), which serves as the control, the experimental had only one round and participants were only provided with basic information on digestate (eg. where it was produced and how it worked on the soil). Participants were also shown a sample of digestate in a container which they could touch and smell.

In the second treatment ‘Treatment 2’ (T2, 55 members), the experimental auction had 5 rounds and bidders were given the same basic information on digestate as in T1.

In the third treatment ‘Treatment 3’ (T3, 56 members), the experimental auction had 10 rounds and the bidders were given the same basic information as in the two previous groups.

In the final 4th treatment ‘Treatment 4’ (T4, 56 members), the experimental auction had 10 rounds, but bidders were told that after the first five rounds they would receive additional information on digestate regarding its chemical properties, its application etc. So, the bidders made their first five bids on the basic information received in the 3 previous treatments. Subsequently, bidders made 5 more bids having received the additional digestate information.

To avoid any issues of bias or affiliation (Corrigan et al, 2011), participants did not receive any kind of feedback across rounds such as who was the winner, the winning bid or the second highest bid representing the market price.

Table 1. Treatment characteristics

| | (T1) | (T2) | (T3) | (T4) |
|---|---|---|---|---|
| Number of Rounds | 1 | 5 | 10 | 10 |
| Basic information | Yes | Yes | Yes | Yes |
| Detailed information | No | No | No | Yes |
| Winning bid feedback between rounds | No | No | No | No |

## *2.2 Hypotheses*

The commitment cost theory posits that WTP for digestate will decline the lower the amount of additional information to be expected. In our design, T1 - the control, is a one-shot experiment in which participants cannot expect any additional information will arise in the context of the experiment. As such, we hypothesize that T1 will yield mean WTP values that exceed the mean WTP values from round one in T2, T3, and T4. Similar reasoning suggests that round one bids in T2, in which participants know four additional rounds will be conducted, will exceed mean WTP in T3 and T4, in which participants know nine additional rounds will be conducted. While it is true that participants do not know exactly what will be learned from the additional rounds, the fact that there is more opportunity to learn should serve to lower round 1 bids in T3 and T4 relative to T2. Finally, we hypothesize explicit promise of additional future information in T4 should result in this treatment yielding the highest mean WTP. We initially test our hypotheses using ANOVA, where the null is that the means across all treatments are equal. If the null is rejected, we proceed with pair-wise t-tests.

## 3. Results

There were no significant differences in the four treatments in terms of gender, age, qualifications, farm income or crop type according to a Fisher's exact test, suggesting these factors cannot explain differences across treatment.

Mean WTP in the four treatments is consistent with the hypotheses derived from the commitment cost theory (Table 2). The average bid was highest for T1 (auction with only 1 round) at €15.82 whereas the lowest average bid was for T3 (auction with 10 rounds) at €5.77. Moreover, T4, the average bid in the first 5 rounds (T4a) was much lower than in the final 5 rounds (T4b) having received the additional information on digestate.

Table 2 – Mean WTP per treatment

| Treatment | Mean | St-Dev |
|---|---|---|
| | [€] | |
| T1 | 15.82 | 16.89 |
| T2 | 13.72 | 12.76 |
| T3 | 5.77 | 8.63 |
| T4 | 11.09 | 9.31 |
| *T4a* | *6.27* | *6.58* |
| *T4b* | *15.92* | *15.10* |

The WTP values in round one decrease across treatments, consistent with the idea that WTP is falling in the expected information.

To determine whether the mean WTP values are statistically different between the four treatments, we conducted an ANOVA test. The value of the F-statistic was 9.12 with a p-value equal to 0.000, which rejects the null of equal means across all four treatments. Pair-wise t-tests indicate significant differences (Table 3). Results indicate differences between treatment T1 and treatments T3 and T4a as well as between treatment T2 and treatments T3 and T4a. No significant difference is found between the WTP of treatments T1 and T2. Moreover, there are significant differences between the WTPs of T3 and T4b. Finally, no significant difference was found between the WTPs of T1 and T4b nor between the WTPs of T2 and T4b.

Table 3 – Pair-wise t-tests

| Treatment | T1 | T2 | T3 | T4a |
|---|---|---|---|---|
| T2 | -2.10<br>*(0.9914)* [a] | | | |
| T3 | -10.06<br>*(0.000)* | -7.96<br>*(0.010)* | | |
| T4a | -9.56<br>*(0.001)* | -7.46<br>*(0.020)* | 0.50<br>*(0.9923)* | |
| T4b | 0.10<br>*(0.9936)* | 2.20<br>*(0.9918)* | 10.16<br>*(0.000)* | 9.65<br>*(0.001)* |

[b] Values in brackets are p-values

## 4. Conclusion

We offered a conceptual explanation for some of the procedural invariance witnessed in experimental studies related to the concept of commitment costs. In our empirical study related to Sicilian farmers' willingness-to-pay for a renewable soil conditioner, we manipulated commitment costs across treatments by altering the number of bidding rounds and the expected amount of information to be gathered about the new product. We found these manipulations produce sizable changes in willingness-to-pay in the hypothesized direction. When participants knew they had the ability to wait and gather additional information, immediate willingness-to-pay is more than 100% lower than in the one-shot condition. Results suggest that procedural invariance need not arise from irrationality or behavioural-economic phenomena but rather are largely explained by the rational theory of commitment costs.

However, while admitting that our method was effective in proving commitment costs, other aspects remain unresolved. It is not sufficient to say commitment costs exist and what their role is, but it's necessary to really understand what they are and if they correlate to consumer's subjective beliefs in credence or experience attributes.

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# 4. Discussion

In the first exploratory study, we noted that Sicily can contribute to the national production of biomethane, also with advantageous condition (by making use of residual biomass with ground-cover crops in annual rotation and not with food and by resorting to a minimum quantity (2% of UAA) of dedicated crops. So we marked that the dissemination of anaerobic digestion plants in the territories of Southern Italy is therefore important as it would mean a higher penetration of renewable energy sources.

In this context, Biogas production by Biogasdoneright principles involves producing an advanced biofuel (biomethane) and making the best use of Sicilian agricultural soils. Here, the production of digestate can determine agronomic, economic, environmental, and social benefits to Sicilian agriculture.

So, if exist the potential to produce biomethane and digestate, when this organic soil improver will be produced, it will be used by farmers? Is it possible a new market for it?

To answer to these questions, we conducted a second study. An experimental auction with farmers and owners.

As revealed by Selvaggi et al. (2018c), there is a positive farmers' WTP for digestate. The results of this specific study show above all farmers' WTP for digestate as an organic soil conditioner for their farms. It confirms therefore that which has been highlighted by other studies – farmers' interest in digestate (Saveyn and Eder, 2014; Dahlin et al., 2015 and 2017). This is a positive result which can help grow the environmental sustainability of anaerobic digestion on farms and increase income from biogas.

These results will be important for biogas industry since digestate is currently mainly used in those geographic areas where anaerobic digesters are widespread but not in the Mediterranean area. Moreover, since the profitability of digesters is traditionally dependent on state subsidies, opening new markets to commercialise digestate could create new income opportunities for digester managers especially in those areas where the spread of anaerobic digesters is still low.

By means of the various treatments applied, we were able to highlight a dual characteristic. Above all, the mean willingness to pay decreased as the bid number rose, that is the delay bidders were subjected to during the experimental auction. In other words, the mean WTP in treatment T1 (only one round; only basic information on digestate for the members; no info on the attributes) was higher than the mean WTP of treatment T2 (five rounds; only basic information on digestate for the members; no info on the attributes) and so on for treatment T3 (ten rounds; only basic information on digestate for the members; no info on the attributes). Furthermore, in the treatment T4 (ten rounds: the first five rounds we give only basic information on digestate for the members, but in the last five round bidders made 5 more bids having received the additional digestate information; bidders were told that after the first five rounds they would receive additional information on digestate regarding its attributes), the highest willingness to pay for digestate was by treatment T4b who received information beyond the basic which all the other groups had been provided with.

This result reflects the mechanism that might happen in the real market where actual purchase may or may not occur after the consumer has been sufficiently informed about a particular good.

Studying the phenomenon more deeply we have discovered that farmers are strongly influenced by how much information is available on digestate. Without information, farmers' WTP decreases drastically. Authors demonstrate that an important condition to expand the digestate market is to provide farmers with the necessary information on the physical and chemical properties of it. It is important to make farmers aware of the benefits that the digestate brings to land if it is used as organic soil improver. So, the lack of information has a potential negative repercussion on willingness to pay or to buy the digestate.

Furthermore, the studies' results confirm previous studies on the existence of commitment costs and their influence on the WTP for a certain asset (Lusk et al., 2004; Bazzani et al. 2017). In fact, a greater WTP for digestate was obtained when the participants were provided with detailed information on its attributes.

In our empirical study related to Sicilian farmers' willingness-to-pay for a renewable soil conditioner, we manipulated commitment costs across treatments by altering the number of bidding rounds and the expected amount of information to be gathered about the new product. We found these manipulations produce sizable changes in farmers WTP in the hypothesized direction. When participants knew they had the ability to wait and gather additional information, immediate willingness-to-pay is more than 100% lower than in the one-shot condition. Results suggest that procedural invariance need not arise from irrationality or behavioural-economic phenomena but rather are largely explained by the rational theory of commitment costs.

All our studies highlighted that the digestate attributes which influence the WTP probably due to commitment costs change according to the influx of extra information. With extra information on digestate, nearly all the attributes influenced, even if negatively, WTP. This has important implications for biogas and digestate since notwithstanding their undoubted interest, the farmers have a negative perception of the organic origin of digestate, the environmental sustainability of the production process, security, price and its effects on soil fertility.

Generally, farmers are strongly influenced by how much information is available on digestate. Without it, farmers' WTP decreases drastically probably due to phenomena correlated to what economic theory calls commitment costs. This signifies that the information provided might have diminished the degree of participant uncertainty about digestate attributes, lowering commitment costs and consequently increasing the WTP. Moreover, confirming the results of previous studies (Corrigan, 2005; Corrigan et al., 2011; Kling et al., 2013), the WTP values obtained in this study change according to how much time participants had to come to a purchase decision. In particular, the WTP for digestate was lowest when participants had more time for their bids, whereas it was highest when there was least decision time.

## 5. Conclusion

The results highlight a positive perception of digestate by farmers which may have important implications for both the organic soil conditioner market as well as for the biogas industry within which digestate is a significant output.

Moreover, the results of this research will have important implications for biogas sector since notwithstanding their undoubted interest, the farmers still have a negative perception of the organic origin of digestate, the environmental sustainability of the production process, security, and its effects on soil fertility.

Understanding attributes affecting farmers' WTP for digestate can promote the market of digestate among farmers with positive effects on soil quality and soil fertility due to its promptly available nutritional contribution to crops.

Expected results of this research will go beyond those of the existing literature because in addition to highlighting commitment costs in the purchase process of digestate, since the research will try to identify which digestate attributes are connected with farmers' WTP to buy digestate by changing wait times and the level of available information. Identifying such attributes in different Mediterranean contexts can contribute to promote the market of digestate and consequently the sustainability of production process in the

Mediterranean basin explaining why commitment costs arise in the digestate purchasing process.

Results of this research will extend current literature since the research will shed some light on which digestate attributes are related to farmers' WTP to buy digestate; but the authors are aware of certain limits in this study such as the location where the research was carried out or the number and appropriateness of attributes of the organic soil conditioners considered. Future research could further explore other digestate attributes which could influence WTP or verify the analysis model we adopted in other locations.

According to these results already done, new studies could evaluate different contexts, different condition of knowledge (generally, digestate is not well-known among farmers in all the Mediterranean area) and validate the methodology and the results.

Every study has limitations. Study limitations can exist due to constraints on research design or methodology, and these factors may impact the findings of the study.

In particular, for this study, the use of different number of rounds across the treatments could have a strong impact on the commitment costs theory results. Probably, if a bigger sample of farmers was involved in the research study, a continues number of rounds could be proposed to determine the exact number of round useful to test the commitment costs theory.

Moreover, after having taken note of the results published in the papers Pappalardo et al., 2018 and 2019 and Selvaggi et al., 2018, about positive farmers’ WTP for digestate, could be interesting to know why people does not entry in the digestate market, asking them a specific question when they offer “0 euros” for the digestate. So, specific future studies should consider the factor affecting the farmers’ choice to enter in the digestate market: the lack of information has a potential negative repercussion on the choice to enter the market, not only on willingness to pay or to buy the digestate?

To reinforce and make more widespread the use of digestate as a soil improver for farms, the causes should be investigated into the commitment costs factor to overcome farmers’ perplexities about the properties of digestate. The lack of specific information on digestate characteristics significantly lowers their WTP due to commitment costs about the real characteristics and benefits for agricultural soil.

However, while admitting that our method was effective in proving commitment costs, other aspects remain unresolved. It is not sufficient to say commitment costs exist and what their role is, but it’s necessary to really understand what they are and if they correlate to consumer’s subjective beliefs in credence or experience attributes.

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# Appendix

## *APPENDIX A – Consent form*

***Research Study***
Eliciting willingness to pay for digestate

***Investigators***

- ✓ Dr. Roberta Selvaggi, University of Catania - Department of Agriculture, Food and Environment (Di3A)
- ✓ Dr. Gioacchino Pappalardo, University of Catania - Department of Agriculture, Food and Environment (Di3A)
- ✓ Prof. Biagio Pecorino, University of Catania - Department of Agriculture, Food and Environment (Di3A)

***Description***
In the present study, we are interested to elicit farmers' willingness to pay for digestate, a solid soil conditioner produced after the anaerobic digestion process to produce biogas. We would like to evaluate the effect of different kinds of information on the price of the digestate. The participants will be undergone to a sort of economic experiment known as "EXPERIMENTAL AUCTION" that will last approximately 30 minutes during which everyone has the possibility of purchasing digestate to use in own farm.
Furthermore, we would like to inform you that the research will take place at the Department of Agriculture, Food and Environment at University of Catania.

***Risks and Benefits***

Your participation will assist in the advancement of knowledge of consumer choice behaviour.

The survey results will become available to academic researchers, farmers, regulators as well as to the wider general public of consumers. This means that this survey could help them to understand the market response for new marketing strategies.

There are no anticipated risks to participating in this study. However, if you feel any inconvenience, please notify it to the researcher at any stage of the study.

***Voluntary Participation***

Your participation in the research is completely voluntary.

***Confidentiality***

Your responses on the survey will be recorded anonymously. No identifying personal information will be collected on the survey. Only basic demographic information (i.e. age, gender, education etc.) will be collected.

***Right to Withdraw***

You are free to refuse to participate in the research and to stop filling out the survey at any time. If you have questions or concerns about this study, you may contact Gioacchino Pappalardo, the principal researcher of this study (University of Catania - Italy), at +39 095 7580341 or by email at gioacchino.pappalardo@unict.it.

## Informed Consent Form

I agree to participate in the research study that is eliciting farmers' willingness to pay for digestate.

I understand the purpose and nature of this study and I am participating voluntarily.

I give my permission for the data to be used in the process of completing a Doctorate Degree, including a dissertation and any other future publications that may arise from this research.

All information will be treated with strict confidentiality. Data identifying the subjects shall be removed and replaced by code identifier that will help to further process the data.

I have understood all the information about this study. My questions and concerns have been answered by the researchers, and I have a copy of this consent form. Therefore, I consent to take part in this research project-

Participants Signature: ___________________________

Name in Block Capitals: __________________________

Place and Date: _________________________________

## *APPENDIX B – Preliminary Survey Questionnaire*

Dear Sir or Madam,

we are researcher charged by the Department of Agriculture, Food and Environment (Di3A) of the University of Catania. We are carrying out an investigation within the research project "*Innovations for the development of biomethane from Mediterranean matrices*" (**INNO-BIOMED**) funded by the Ministry of Agriculture (Mipaaf).

SQ_01 Are you over 18 years old? ☐ Yes ☐ No

SQ_02 Are you owner or manager of the farm?

☐ Yes ☐ No

SQ_03 Are you involved in the purchase process of technical equipment (fertilizers, seeds, soil improvers, etc.) in the company?

☐ Yes ☐ No

SQ_04 Did you use soil conditioners on the farm or would you be interested in doing so?

☐ Yes ☐ No

*(If the respondent answers "YES" (FOR ALL QUESTIONS), please proceed with the description of how our survey will be conducted and ask for the personal information for the next auction. Show him/her the brochure.*

*In case of ONLY ONE negative answer, the questionnaire ends and we thank the respondent for his/her contribution).*

**Well, you are the right person to participate in our research!!**

Before participating in our research, I must ask you if you are willing to go ___________ *(specific period)* to _________________ *(specific location)*, to undergo a sort of economic experiment called "EXPERIMENTAL AUCTION" which will last about an hour.

You will be asked to evaluate the possibility of buying digestate, an organic soil improver produced at the end of the anaerobic digestion process, through a specific questionnaire and an "economic experiment".

You will be asked how much you are willing to pay for the product we will show you, considering however that these are organic soil improvers and not chemical fertilizers. The peculiarity of this research activity is that you will use real products that you can really buy if you are interested.

I would like to point out that if you are interested in participating in our experiment, but are not interested in buying the product in question at the time of the survey, you will not be forced to buy the product.

The aim of this experiment is to understand how much you are really willing to pay for certain products and that is why real products and real money are involved. For this reason, should you agree to participate, to thank you and reward you for your time, we will give you a FOOD PACKAGE worth about 10,00 Euro.

Now, before starting a first questionnaire of about 10 minutes, I specify that you must provide us your email and phone number, so we can contact you to give you exact information about the time and day on which the experimental auction will take place. It will be a mutual exchange of contacts: we will also leave you our contacts and we will be at your complete disposal for any clarifications.

I remind you that your participation is, however, absolutely voluntary and your answers will remain confidential and will be treated in compliance with current privacy laws.

Q_01 ID Questionnaire (n°): |__|__|__||__|

Q_02 Name and Surname: ______________________

Q_03 Email: ______________________

Q_04 Phone: ______________________

Q_05 ID Interviewer ______________________

Q_06 Data: dd. |__|__| mm. |__|__| yy. 2017

Q_07 Start Time: |__|__| :|__|__| (hh:mm)

Please tell me approximately the days and time when you would be available to participate in our survey.

| DATA | I TURN | II TURN | III TURN | IV TURN | V TURN |
|---|---|---|---|---|---|
| ☐ Monday, dd/mm/yy | ☐ hh:mm – hh:mm | ☐ hh:mm – hh:mm | ☐ hh:mm – hh:mm | ☐ hh:mm – hh:mm | ☐ hh:mm – hh:mm |
| ☐ Tuesday, dd/mm/yy | ☐ hh:mm – hh:mm | ☐ hh:mm – hh:mm | ☐ hh:mm – hh:mm | ☐ hh:mm – hh:mm | ☐ hh:mm – hh:mm |
| . . . | | | | | |
| ☐ Friday, dd/mm/yy | ☐ hh:mm – hh:mm | ☐ hh:mm – hh:mm | ☐ hh:mm – hh:mm | ☐ hh:mm – hh:mm | ☐ hh:mm – hh:mm |

*(ATTENTION: Calendarize groups of 5 or 10 people in turn, no more or less)*

## Questionnaire

This questionnaire is part of a research conducted by the Department of Agriculture, Food and Environment (Di3A) of the University of Catania as part of a research project funded by the Ministry of Agriculture. The research aims to know the opinions of farmers on the digestate and their possible willingness to buy it as an organic soil improver. We ask you to give us about 10 minutes of your time. Please answer all questions. We assure you that all answers will be used only for the specific purpose of this research.

**Thank you for your time and contribution.**

| | | |
|---|---|---|
| NQ_01 | Have you ever heard of digestate and how it is produced and what is it for? | ☐ Yes<br>☐ No |

BW **What characteristics of the organic soil improver are important for YOUR purchase decision?**

Now we ask you to choose, among the 5 characteristics of organic soil improvers, which you think is the most important and which is the least important.

We will repeat the same type of question several times, but each time the characteristics you have to compare change.

*(Show the table explaining the attributes in case the respondent is uncertain about the meaning of one or more of them (natural product, safety, etc.)).*

BW_01 When purchasing an organic soil improver, which of the following aspects is the most important and which is the least important? ***(only one choice per column)***

| Most important | | Least important |
|---|---|---|
| ☐ | Organic origin | ☐ |
| ☐ | Soil fertility | ☐ |
| ☐ | Local production | ☐ |
| ☐ | Microbial activity | ☐ |
| ☐ | Safety | ☐ |

BW_02 When purchasing an organic soil improver, which of the following aspects is the most important and which is the least important? ***(only one choice per column)***

| Most important | | Least important |
|---|---|---|
| ☐ | Soil fertility | ☐ |
| ☐ | Natural product | ☐ |
| ☐ | Local production | ☐ |
| ☐ | Safety | ☐ |
| ☐ | Organic origin | ☐ |

BW_03 When purchasing an organic soil improver, which of the following aspects is the most important and which is the least important? ***(only one choice per column)***

| Most important | | Least important |
|---|---|---|
| ☐ | Price | ☐ |
| ☐ | Soil fertility | ☐ |
| ☐ | Microbial activity | ☐ |
| ☐ | Environmental sustainability | ☐ |
| ☐ | Safety | ☐ |

BW_04 When purchasing an organic soil improver, which of the following aspects is the most important and which is the least important? ***(only one choice per column)***

| Most important | | Least important |
|---|---|---|
| ☐ | Price | ☐ |
| ☐ | Local production | ☐ |
| ☐ | Soil fertility o | ☐ |
| ☐ | Organic origin | ☐ |
| ☐ | Environmental sustainability | ☐ |

BW_05 When purchasing an organic soil improver, which of the following aspects is the most important and which is the least important? ***(only one choice per column)***

| Most important | | Least important |
|---|---|---|
| ☐ | Price | ☐ |
| ☐ | Organic origin | ☐ |
| ☐ | Safety | ☐ |
| ☐ | Local production | ☐ |
| ☐ | Environmental sustainability | ☐ |

BW_06 When purchasing an organic soil improver, which of the following aspects is the most important and which is the least important? ***(only one choice per column)***

| Most important | | Least important |
|---|---|---|
| ☐ | Microbial activity | ☐ |
| ☐ | Soil fertility | ☐ |
| ☐ | Natural product | ☐ |
| ☐ | Environmental sustainability | ☐ |
| ☐ | Safety | ☐ |

BW_07 When purchasing an organic soil improver, which of the following aspects is the most important and which is the least important? ***(only one choice per column)***

| Most important | | Least important |
|---|---|---|
| ☐ | Environmental sustainability | ☐ |
| ☐ | Price | ☐ |
| ☐ | Natural product | ☐ |
| ☐ | Microbial activity | ☐ |
| ☐ | Local production | ☐ |

BW_08 When purchasing an organic soil improver, which of the following aspects is the most important and which is the least important? ***(only one choice per column)***

| Most important | | Least important |
|---|---|---|
| ☐ | Organic origin | ☐ |
| ☐ | Natural product | ☐ |
| ☐ | Environmental sustainability | ☐ |
| ☐ | Microbial activity | ☐ |
| ☐ | Price | ☐ |

BW_09 When purchasing an organic soil improver, which of the following aspects is the most important and which is the least important? ***(only one choice per column)***

| Most important | | Least important |
|---|---|---|
| ☐ | Microbial activity | ☐ |
| ☐ | Safety | ☐ |
| ☐ | Natural product | ☐ |
| ☐ | Organic origin | ☐ |
| ☐ | Price | ☐ |

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## SOCIO-DEMOGRAPHIC SECTION

SD_01 Gender ☐ Female ☐ Male

SD_02 Year of birth |__|__|__|__|

SD_03 Maximum level of education achieved

- ☐ Elementary school license
- ☐ Middle school license
- ☐ High school diploma
- ☐ Degree or more
- ☐ Other (specify) __________

SD_04 What is the average income of your farm??

☐ less than 10,000 €/year
☐ between 10,000 and 19,999 €/year
☐ between 20,000 and 39,999 €/year
☐ between 40,000 and 49,999 €/year
☐ over 50,000 €/year

SD_05 Which is or which are the production systems within your farm?

☐ Arable crops
☐ Fruits
☐ Citrus fruits
☐ Zootechnical
☐ Open field horticultural
☐ Greenhouse horticultural
☐ Other (specify) ________________

***End of the questionnaire!!***

***Thank you for your time and your contribution.***

Q_08. End time: |__|__|:|__|__|

## *APPENDIX C – Auction procedure protocol*

*Participants arrive at the room where the experimental auction will be carried out.*

*Participants are assigned ID number and an information sheet about digestate (they will be randomly assigned to different sub-groups).*

*Participation is accommodated to their seat.*

**Introductory instructions**

Thank you for agreeing to participate in today's session. This session will last 30-45 minutes. By the end of the session, you will receive a *food package* worth about 10,00 Euro for your participation. As you entered the room, you should have been assigned an ID number, in which you will use this ID number to identify yourself during this research session. You will be randomly assigned to the sub-group of 5 to 7 persons and you will proceed the auction within your group.

I want to assure you that the information you provide will be kept strictly for the research purpose.

Before we begin, I want to emphasize that your participation in this session is voluntary. If you do not wish to participate in the experiment, please say so it now. Non-participants will not be penalized in any way. **Importantly, please do not talk with each other during this session.**

In today's session, **we are interested in your preferences for a type of soil conditioner, the so-called "digestate"**.

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*<<Explain the auction mechanism and the practice section>>*

**Instruction to explain the second price auction mechanism and practice section with pasta**

Basically, we are interested in your preferences for the **digestate to be used as soil conditioner** therefore, we will ask you to indicate the **most** you are willing to pay (if anything) to purchase this product. You can always indicate "*zero*" if you are not interested at all in the product. By the end, you will have an opportunity to win the product and you will have to pay for it.

In order to let you understand how the auction works, we are now conducting a *practice section* with generic pasta (500 g pack).

Before then, let me explain how the auction will be proceeded:

1. First, each of you will see a pack of pasta in front of the room. You will also have a chance to investigate the product and read its information.

2. You will be asked to indicate the **most** you are willing to pay for this pasta (so called, "bid"). Remember that you can always write *zero* if you are not interested in the product at all. Your bids are *private information* and should not be shared with anyone. After you have finished writing your bids, you will have to wait until others finish their writing.

3. Then, we will rank the bid from highest to lowest **within your group**. In each groups, the person with the **highest bid** will **win** the auction and **the 2nd highest bid** amount for the pasta is **its price**.

4. The **winning bidder's ID of your group** will be shown.

5. Afterward, we will re-conduct the auction for 4 additional round. Therefore, in total you will bid 5 times.

6. At the completion of the 5th round, we will randomly draw a number 1 through 5 to determine the binding round. For example, if we randomly draw the number 4, then we will focus only the winning bidder and price in round 4 and ignore outcomes from other rounds. Note that all rounds have an equally chance of being binding, therefore, you shall bid sincerely for every rounds.

7. Once the binding round has been determined, ***if it is in the real auction,*** the winner bidder will go to the administrator to pay the 2nd highest bid amount for that binding product, and receive the product, receipt and gadget. While all other respondents will receive the gadget.

I just want to note briefly that you will have a chance to win the product **within your group**. And if you bid lower than its real value, you might risk to have no chance to get the product. If you bid higher than its real value you might win and pay for the amount that you actually do not want to pay. Therefore, your best strategy could be to bid sincerely what you think it is real value of the products for you.

<u>*Example*</u>

Suppose there were five persons participating in an auction of pasta for 5 rounds. After the 5th round, the 3rd round was randomly selected to be binding round. Suppose in the 3rd round, respondent #1 bid €0.7 for pasta, respondent #2 bid €0.4, respondent #3 bid €0, respondent #4 bid €1 and respondent #5 bid €0.8. Who would win the auction? Respondent#4 will win the auction because she/he bid the highest amount. How much respondent#4 has to pay? Respondent#4 will pay €0.8, which is the 2nd highest bid amount. Respondent#1, #2, #3, #5 would pay nothing and would leave without pasta.

Do you have any question before we begin?

<< *Begin the practice section*>>

1. Please take a look at the pasta.
2. How much are you willing to pay for this pasta?

*<<Let respondents bid for pasta 5 times, the winner's ID will be shown at each rounds for each groups.>>*

3. After the 5th round, we will draw the binding round.

4. The binding round is <<...>>
5. The ultimate winner's ID of each groups will be shown.
6. Do you have any question?

---

*<<Begin the auction section>>*

**Instruction for Digestate auction**

Here we come to the auction, which will involve the real transaction of money and product. In this auction, we are interested in your preferences for **<u>digestate to be used as soil conditioner</u>**. Each of you will see in front of the room a sample pack of digestate. You will also have a chance to investigate the product and read its information.

*<<Let respondents see and investigate the sample of digestate>>*

Please go through information sheet with me; you will see the description of digestate.

*<<Show the information sheet>>*

*<<Coordinator read the information at the same time>>*

<<De*pending on the treatment scheduled by experimental design, participants will receive different information on digestate. Thus, the control groups will receive generic*

*information on digestate whereas the tested group will receive detailed information (including a small video) on digestate such as how it is produced, its properties etc.>>*

**Information sheet**
(Detailed information of digestate's properties will be fulfilled soon!)

Now we will give you the opportunity to participate in an auction to purchase **a ton of digestate to be used as soil conditioner within your farm**. The process would be the same as pasta auction. The differences are that in this auction, you will be asked to indicate the **most** you are willing to pay for buying a ton of digestate. You will bid 1 round *(<<or 5 rounds or 10 rounds depending of treatment>>).*

*<<in the treatments with more than one round, it must be explained that a binding round will be drawn>>*

The binding round will be drawn from the number 1 to 5 (*<<or 1 to 10 depending of treatment>>*). Do you have any question before we begin?

The auction procedure will be as followed:

1. You will be asked to indicate the **most** you are willing to pay for buying **a ton of digestate**. Remember that you can always write *zero* if you are not interested in the product at all. Your bids are *private information* and should not be shared with anyone. After you have finished writing your bids, you will have to wait until others finish their writing.

2. Then, we will rank the bid from highest to lowest **within your group**. In each group, the person with the **highest bid** will **win** the auction and **the 2nd highest bid** amount for the digestate is **its price**.

3. **Winning bidder's ID of your group** will be shown in front of the room by coordinator.

*<<in the treatments with more than one round, we proceed as follow>>*

3.1 After posting the winner's ID for the 1st round, we will re-conduct the auction for four additional rounds (<< *or for 10 additional rounds or for 4+5 rounds*>>).

4. Now the auction begins.

*<<Respondents will bid for 1 or 5 or 10 rounds>>*

*<<in the treatments with only one round, we proceed as follow>>*

5. Now, the winners (the highest bidders) for each group are notified by coordinator that they will pay the 2nd highest bid and will receive the binding product, while the other participants will not pay anything.

*<<in the treatments with 5 or 10 rounds, we proceed as follow>>*

6. The 5th round (*or the 10th round*) has been finished. Now we will randomly draw a number 1 through 5 (*or 1 through 10*) to determine the binding round. Note that every round has an equally chance of being binding.
7. The binding round is <<…>>
8. Now, the winners (the highest bidders) for each group are notified by coordinator that they will pay the 2nd highest bid from the binding round and will receive the binding product, while the other participants will not pay anything.

*<<End of the Auction>>*

9. Thank you very much for your participation. Please go to the administrative to receive your participation gift and/or to pay and receive your product.

*<<Participants go to the cashier; the winners pay the price and receive an invoice and a voucher which entitles him to pick up a ton of digestate at a dealer of digestate previously identified. All participants receive a food package worth about 10,00 Euro as a reward for having taken part in the auction>>.*

## *APPENDIX D – Organic soil conditioners' attributes*

| | |
|---|---|
| *Organic origin* | Organic soil conditioners are different to chemical fertilisers |
| *Soil fertility* | Organic soil conditioners have positive effects on soil fertility |
| *Environmental sustainability* | Organic soil conditioners production has no environmental impact |
| *Local production* | Organic soil conditioners are sourced locally |
| *Safety* | Organic soil conditioners are safe to use because they are not chemical products |
| *Price* | Organic soil conditioners costs |
| *Natural product* | Organic soil conditioners are natural products which contribute to producing healthier foods |
| *Microbial activity* | Organic soil conditioners improve microbial activity in the soil because they are rich in organic substances |